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USE OF MANGANESE IN STEELMAKING AND STEEL PRODUCTS AND TRENDS IN THE USE OF MANGANESE AS AN ALLOYING ELEMENT IN STEELS

Congress of the United States
Office of Technology Assessment

February 7, 1983

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FINAL REPORT

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Contract No. 233-5870.0

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I. INTRODUCTION AND BACKGROUND

Manganese is a principal constituent of iron and steel products, and the manufacture of iron and steel accounts for about ninety percent of the domestic consumption of manganese.[1,2] Other uses of manganese include the production of aluminum, copper, and magnesium alloys; the manufacture of dry cell batteries containing manganese dioxide; the manufacture of a variety of chemical, petrochemical, and pharmaceutical products; the manufacture of special refractory, ceramic, and glass products; and the manufacture of welding rods primarily for ferrous products. All of these additional uses when combined represent less than ten percent of the manganese consumption in the United States.

The purpose of this report is to present a concise description of the current use of manganese in iron and steel production and to assess technological developments that may affect the use of manganese in iron and steel production through the year 2000. In fulfilling this objective it is necessary to consider three major technological topics as presented below.

- The manner and form in which manganese is added during the production of iron and steel.
- The function of manganese as a constituent and alloying element in iron and steel products.
- The compositional specifications of iron and steel products.

In the next three sections, brief descriptions of iron and steel production, the functions of manganese in iron and steel, and the manganese specifications of iron and steel products are presented. In subsequent chapters, detailed information on current use, technological developments, and twenty-year forecasts are presented.

A. Manganese in Iron and Steel Production

Ironmaking

The principal source of crude iron in the United States is molten iron produced in blast furnaces (sometimes called hot metal or pig iron, although the latter term more properly describes cast and solidified blast furnace iron). The blast furnace is a reduction process wherein the iron oxide contained in iron ores (beneficiated, pelletized, or sintered) is reduced to metallic iron by the action of coke and gases containing carbon monoxide and hydrogen. The iron produced in blast furnaces contains substantial amounts of other elements including about 4.4 percent by weight of carbon and lesser amounts of silicon (~ 0.7%), phosphorous (~ 0.2%), manganese (~ 0.7%), and sulphur (~ 0.03%). Blast furnace iron must be refined in subsequent processes to yield commercially useful iron and steel products. Manganese is a constituent of several of the items charged to the blast furnace. The iron ores contain small but significant amounts of manganese. Some recycled iron and steel scrap and steelmaking slag containing manganese is charged to blast furnaces. In addition, ore sinter may contain some recovered manganese-bearing dusts and waste materials. From fifty to eighty percent of the manganese charged to blast furnaces is recovered in the molten iron. Typically, the average value of recovery is 75 percent with the remainder lost to the blast furnace slag.

Much smaller amounts of crude iron (Sponge Iron, D.R.I.) are produced in direct reduction processes from iron ore (pellets, etc.). Although DRI may contain some manganese from the starting ore, it is present as an oxide or silicate rather than in reduced metallic form. Upon melting, usually in the electric arc furnace, the manganese oxide is lost to the resultant steelmaking slag.

Some molten iron is produced in cupolas and other cast iron foundry furnaces. The charge materials usually consist of scrap iron and steel and pig iron. Normally, manganese recovery in the iron is about 50 percent in such foundry melting

operations with the remainder of the manganese lost to the slag.

Hot metal, or molten blast furnace iron, is often desulphurized in a separate process station before delivery to the oxygen steelmaking furnaces. This separate process step is called external desulphurization. Figure 1 is a schematic diagram of metallic inputs and flows in iron and steelmaking systems.

Steelmaking

The term steelmaking describes the high-temperature processes in which crude forms of iron-bearing material are heated, refined, and combined with alloying elements to yield molten steel of the desired temperature and chemical composition. The principal forms of iron-bearing material used in the manufacture of steel are molten crude iron from blast furnaces and solid iron and steel scrap. To a lesser extent, pig iron (solidified blast furnace iron), directly-reduced-iron (D.R.I., sponge iron), high grade iron ores, and ferroalloys are used to provide raw iron for steel production. The high-temperature processes of steelmaking include an initial step in which the crude iron is brought to a temperature near 1600°C and partially refined, and a series of finishing steps in which the impurity and alloying element contents are closely adjusted.

The primary step in steelmaking is accomplished either in basic oxygen steelmaking furnaces (B.O.P., Q-B.O.P., L.D.-AC, etc.), electric arc furnaces, or, to a lesser and diminishing extent, in basic open hearths. The use of these three primary systems in the United States and other parts of the world are shown in Table I.[3,4] The crude metallic feed to electric arc furnaces (EAF) consists almost entirely of scrap iron and steel and D.R.I. The basic oxygen furnaces must be fed a mixture of "hot metal" (crude molten iron from the blast furnace), scrap iron and steel, D.R.I., and high-grade iron ore with not less than 70 percent hot metal. Fuel-fired open hearths can accept feeds varying widely in both hot metal and solid metallic content but current usage favors charges that consist

Fig. 1. Metallic Inputs and Flows in Steelmaking Systems

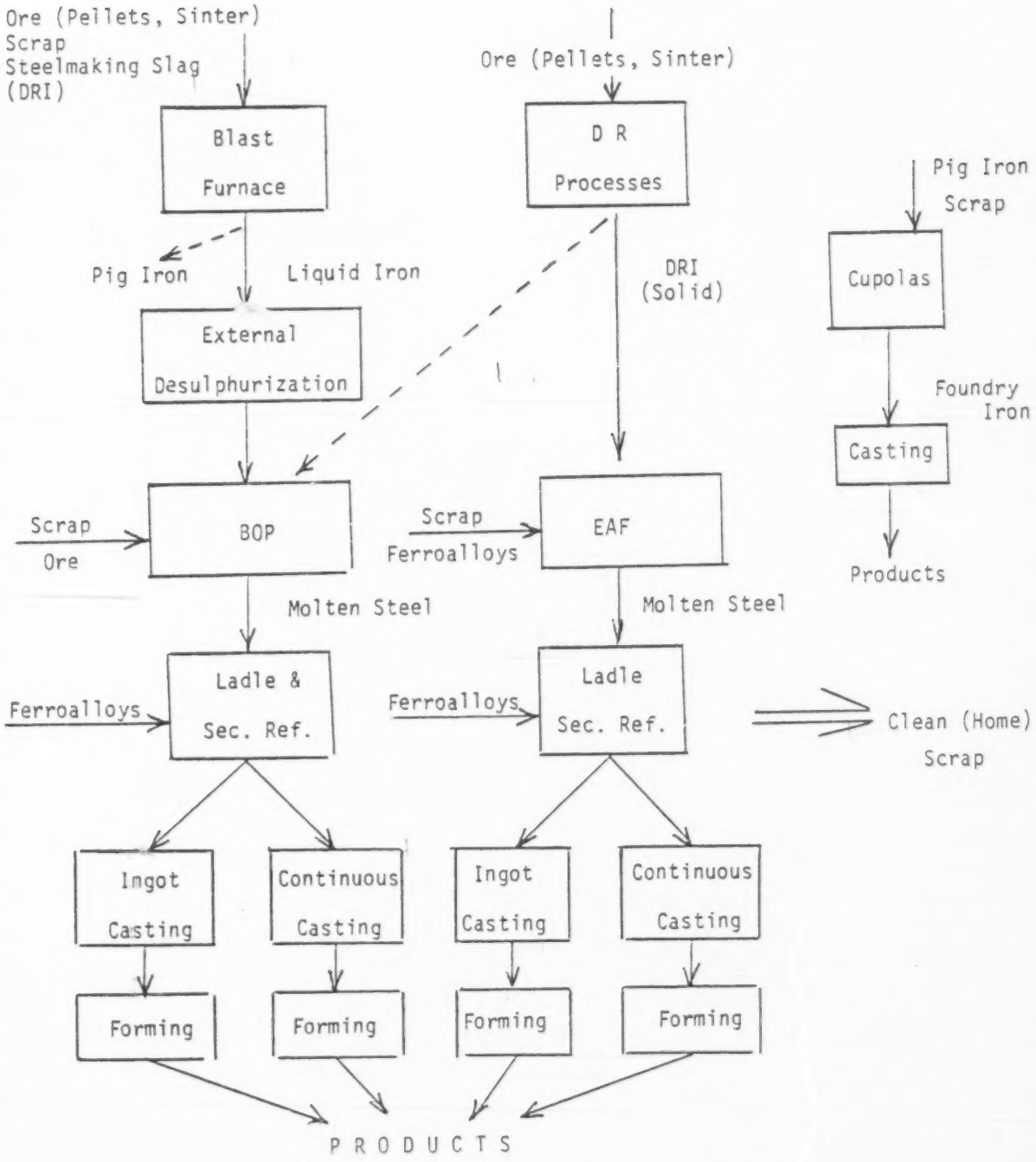

Table I

Raw Steel Production by Process in the U.S. (Millions of Short Tons)[1]

Year	Open Hearth	Basic Oxygen Proc.[2]	Electric Arc Proc.	Total
1981	13.45 (11.1%)	72.23 (60.6%)	34.15 (28.3%)	120.83
1980	13.05 (11.7%)	67.62 (60.4%)	31.17 (27.9%)	111.84
1979	19.16 (14.0%)	83.26 (61.1%)	33.93 (24.9%)	136.34
1978	21.31 (15.6%)	83.48 (60.9%)	32.24 (23.5%)	137.03
1977	20.04 (16.0%)	77.41 (61.8%)	27.88 (22.2%)	125.33
1976	23.47 (18.3%)	79.92 (62.5%)	24.61 (19.2%)	128.00
1975	22.16 (19.0%)	71.80 (61.6%)	22.68 (19.4%)	116.64
1974	35.50 (24.3%)	81.55 (56.0%)	28.67 (19.7%)	145.72
1973	30.78 (26.4%)	83.26 (55.2%)	27.76 (18.4%)	150.80
1972	34.94 (26.2%)	74.58 (56.0%)	23.72 (17.8%)	133.24
1971	35.56 (29.5%)	63.94 (53.1%)	20.94 (17.4%)	120.44
1970	48.02 (36.5%)	63.33 (48.2%)	20.16 (15.3%)	131.51
1969	60.89 (43.1%)	60.24 (42.6%)	20.13 (14.3%)	141.26
1968	65.84* (50.1%)	48.81 (37.1%)	16.81 (12.8%)	131.46
1967	70.69* (55.6%)	41.43 (32.6%)	15.09 (11.8%)	127.21

(1) One short ton is 2000 pounds mass. The term tonne refers to the metric ton or 1000 kg. One tonne is equivalent to 1.10 short ton.

(2) The Basic Oxygen Processes include BOP, Q-BOP, and all of the other modifications of the pneumatic oxygen steelmaking processes.

* Bessemer included with open hearth.

primarily of scrap. The basic oxygen furnaces (B.O.P.) must be operated in conjunction with blast furnace plants including cokemaking facilities because they depend upon a supply of hot metal. For this reason, oxygen steelmaking furnaces are utilized only in large integrated steel plants with production capacities greater than one million tonnes per year. Electric arc furnaces may be operated wherever there is an adequate supply of scrap or D.R.I. and a combination of other favorable economic conditions sufficient to sustain a plant with an annual production capacity greater than 50,000 tonnes.

Ladle and Secondary Refining

Steel produced in either the B.O.P. or E.A.F. processes is only partially refined. The molten steel is transferred to ladles and special refining vessels wherein final adjustment of chemical composition is achieved. The nature and extent of secondary refining and alloying varies widely depending upon the grade of steel being produced and the final product for which the steel is intended.

The principal impurity elements to be removed during primary steelmaking are excess carbon, phosphorous, sulphur, and silicon. In addition, the final oxygen, hydrogen, and nitrogen contents must be strictly limited. Where excessive amounts of tramp elements such as copper and lead contained in the scrap are retained in the steel, the steel may be rendered unsuitable for many applications. The final steel composition and cleanliness* must be adjusted through the addition of ferroalloys, deoxidizers, and final desulphurizing and sulphide shape control additions. The secondary and ladle refining processes include the use of nitrogen and argon purging, vacuum degassing, lime and rare earth injection techniques, and special deoxidation procedures.

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* The term "cleanliness" is used to describe the extent to which the steel is free of undesirable non-metallic inclusions. Non-metallic inclusions include oxides, sulphides, entrapped slag and refractory particles, and incorporated bits of foreign material.

The hot metal and scrap used in steelmaking contain significant amounts of manganese; however, during the heating, melting, and primary oxidation refining most of the manganese is lost to the steelmaking slag.* Because of technological changes, the recovery of manganese during steelmaking is increasing. However, fifty to eighty percent of the manganese is lost to the slag depending upon the final carbon content and other operating variables. A small amount of steelmaking slag is recycled in the blast furnace.

Manganese in the form of ferroalloys is added to molten steel during ladle and secondary refining. This represents the primary addition of "virgin" manganese in the steelmaking sequence. Specific figures on current usage will be cited in a later chapter.

Ingot and Continuous Casting

Molten steel is cast either into ingots in conventional practice or directly into slabs and billets in modern continuous casting machines. The latter practice offers many advantages including improved product quality, increased yield of product from molten steel, lower energy requirements, and substantial cost savings. Continuous casting increases the yield of product from molten steel and, thereby, decreases the amount of "home" scrap generated. Therefore, the quantity of manganese required per unit of steel products is less when steel is cast continuously. The savings in manganese (and other additives to molten steel) result primarily from the elimination of loss when home scrap must be reprocessed through the steelmaking furnaces. Table II shows some recent trends on product yield[5] and the growing importance of continuous casting.[6] Based on planned installations, the continuous casting capacity in the U.S. should be 57.26 million tons per year by the end of 1984 compared with 1981 capacity of about 23 million tons.[7]

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*The oxidation of Mn in hot metal and the resultant incorporation of the MnO in steelmaking slag is important in the BOP because of its fluxing action. Low hot metal manganese content must be compensated by the addition of other fluxing agents, most commonly fluorspar (CaF_2).

Table II

Yield of Raw Steel From B.F. Iron and Scrap, Yield of Shipments From Raw Steel, and Growth of Continuous Casting in the U.S.(Millions of Short Tons)

Year	B.F. Iron[1]	Scrap[2]	Raw Steel	Shipments	% Cont. Cast.
1981	70.86(50.2%)[3]	70.47(49.8%)[3]	120.83(85.5%)[4]	87.01(72.0%)[5]	21.1
1980	66.11(49.8%)	66.56(50.2%)	111.84(84.3%)	83.85(75.0%)	20.3
1979	83.31(51.9%)	77.19(48.1%)	136.34(84.9%)	100.26(73.5%)	16.9
1978	83.57(52.3%)	76.29(47.7%)	137.03(85.7%)	97.94(71.5%)	15.2
1977	77.14(52.7%)	69.30(47.3%)	125.33(85.6%)	91.15(72.7%)	12.5
1976	82.04(54.5%)	68.43(45.5%)	128.00(85.1%)	89.45(69.9%)	10.6
1975	72.84(53.7%)	62.84(46.3%)	116.64(86.0%)	79.96(68.6%)	
1974	90.50(52.7%)	81.07(47.3%)	145.72(84.9%)	109.47(75.1%)	
1973	96.14(53.8%)	82.47(46.2%)	150.80(84.4%)	111.43(73.9%)	
1972	85.27(53.7%)	73.42(46.3%)	133.24(84.0%)	91.81(68.9%)	

(1) Blast furnace iron consumed in steelmaking. About 3 to 4 million tons of blast furnace iron was either sold or used for production of cast irons in 1981.

(2) Total scrap consumed includes "home" scrap and purchased scrap. About 57 percent of scrap is recycled in EAF and 43 percent in BOP and Open Hearth.

(3) Percentage of metallic charge to steelmaking (B.F. Iron plus Scrap).

(4) Yield of Raw Steel From Metallic Charge (B.F. Iron plus Scrap).

(5) Yield of Products From Raw Steel.

B. The Functions of Manganese in Steel and Steelmaking

Manganese is second only to carbon in importance as an alloying element in steel. It affects the properties of steel in a variety of ways throughout the entire steelmaking process. In this section, the major functions and effects of manganese in steel are outlined.

Sulphur Control

Except for a special class of steels described in more detail below, sulphur is a tramp element which enters all iron and steelmaking cycles from scrap and coke. The source of the problems caused by sulphur in steel derives from compounds of iron and sulphur (FeS). In general, the hot working of steel is conducted at temperatures where the compound FeS is either liquid or extremely plastic. These temperatures are encountered in the early stages of steel deformation in the preparation of wrought products. Because FeS tends to form at interfaces (e.g., grain boundaries) its presence severely weakens the steel at high temperatures and causes cracking during the working operation. When this occurs, the steel is said to suffer from "hot shortness." There is also a severe detrimental effect caused by FeS on the mechanical properties of ferritic steels at low temperatures. In particular, increased sulphur decreases the toughness of steel.

To minimize these effects, it is important to limit the sulphur content of steels to levels typically below 0.05 wt. percent. In addition, an effective way of reducing the deleterious effect of manganese, from an economic standpoint, is to maintain the manganese content above certain levels. Sulphur combines preferentially with manganese to form MnS, a compound which is chemically more stable than FeS. In addition, MnS is solid at typical hot working temperatures and occurs as equaxed or "blocky" precipitates which are readily deformed during the hot working

operations. Both high temperature and low temperature properties are improved although, indeed, good low temperature ductility is consistent with a low overall sulphur content in the steel.

In some steels the MnS content is increased in order to improve machinability. The steels are known as resulphurized or resulphurized and rephosphorized grades and find service in applications where considerable machining is needed; e.g., in the production of cams and gears. By increasing the number (per unit volume) of MnS particles in the steel, the chip formation process is made easier which improves surface finish and metal removal rates, and increases tool life.

As noted earlier, it is becoming common to desulphurize blast furnace iron to sulphur contents less than 0.01 percent before it is transferred to steelmaking. In addition, the use of secondary and ladle refining techniques is tending to lower the sulphur content in finished steels to values less than 0.01 percent. Hence, the need for manganese solely for sulphur control is diminishing.

Deoxidation

The amount of oxygen dissolved in liquid steel is of considerable importance in determining the structure of an ingot after pouring and solidification. This is a consequence of the reaction of oxygen with carbon to produce carbon monoxide gas during solidification and the trapping of this gas leading to defects known as blowholes. Reduction of the oxygen content of the steel (deoxidation) is readily accomplished in the ladle by the addition of certain elements which are strong oxide formers, thereby removing the dissolved oxygen from the bath. This process produces a killed* steel. Important deoxidizers added for this purpose include aluminum, silicon, and manganese. In addition, combinations of elements including calcium, barium, titanium, columbium, and vanadium are also used.

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*The term "killed" derives from the fact that the liquid lies quiet in the mold while it solidifies. If the steel has not been killed it effervesces during solidification.

Solid Solution Strengthening

When one element is dissolved in another, the latter (the solvent) generally becomes stronger. This effect is known as solid solution strengthening. One of the functions of alloy additions to iron is to increase its strength but the effectiveness of the common alloying elements in serving this purpose varies markedly among them. By effectiveness we refer specifically to the increase in strength per weight percent of the element dissolved. Of course, the most pronounced influence on the strength of steel is achieved by heat treatment affecting the microstructure and the morphology and dispersion of carbides. However, in ferritic steel products which receive no heat treatment, alloy additions furnish an important method for increasing strength. Among the common alloying elements in ferritic steels the order of decreasing effectiveness in solid solution strengthening of steel appears to be as follows: silicon, manganese, nickel, molybdenum, vanadium, tungsten and chromium. While silicon ranks highest on this list its use as a solid solution strengthener is accompanied by a relatively severe detrimental effect, namely loss of ductility. Thus manganese has great utility in this regard.

Hardenability

As noted above the most potent method for altering the strength of steel is heat treatment. A common heat treatment cycle involves heating the steel in the austenite range for sufficient time to dissolve the carbides and homogenize the alloying elements (austenitization), cooling rapidly enough to form martensite (quench), and reheating the martensite to toughen it (tempering). Heat treatment cycles vary and the details of the microstructural changes that occur during any particular cycle are complex. Nevertheless, in general one of the most important functions of alloying elements in steels is to facilitate the formation of martensite. Hardenability provides a quantitative

measure of the cooling rates necessary to form a certain amount of martensite during the quench but a detailed analysis of this factor is beyond the scope of this report. It suffices to point out that additions of the common alloying elements namely molybdenum, manganese, chromium, silicon and nickel increase hardenability, i.e., reduce the cooling rate requirements. This list also approximately ranks the effectiveness of these elements in order of decreasing effectiveness, although in combination, synergistic effects can change the order. The important point, however, is that manganese is one of the most vital alloying elements in influencing the response of steel to heat treatment.

An allied effect of some alloying elements in steel concerns their influence on the shape and distribution of iron carbides. This effect can be important in welding wherein the thermal excursion may produce a continuous iron carbide film on the grain boundaries leading to brittleness of the weld. In this regard, manganese in steel tends to enhance weldability by resisting the development of such film.

Wear Resistance

One of the most important properties of iron, from a technological view, is the transformation from the body centered cubic or ferritic form, stable at room temperature, to the face centered cubic or austenitic form which occurs at about 1670°F. Manganese, like nickel, lowers this transformation temperature and as a consequence is termed an austenite stabilizer. In high carbon steels, additions of manganese to levels in excess of about ten weight percent can produce steels which are austenitic at room temperature. One of the most important properties of austenitic steels is that their strength increases markedly as they are deformed and they have excellent resistance to fracturing under impact conditions. These properties are critical for wear resistance. The austenitic manganese steels are particularly useful in this regard as they display exceptional wear resistance

compared to other steels. These steels, also called Hadfield's steels after their inventor, serve many industrial requirements, economically, where abrasion and impact resistance are needed. Chief applications are in construction, mining,quarrying, oil-well drilling, steelmaking, manufacturing of cement and clay products, railroading, dredging and lumbering. Another specialty steel called "high manganese non-magnetic steel" is being developed for use in powerful magnets at low temperatures.*

C. Manganese Contents of Ferrous Alloys

Steels

Steels can be divided into two broad groups; carbon steels and alloy steels. The main constituents of carbon steels are iron, carbon and manganese, with manganese present up to a maximum of 1.65 percent. An alloy steel either contains a greater quantity of manganese or significant concentrations of other alloying elements. A large variety of compositions are produced and all, at present, contain manganese. However, there is no systematic tabulation of steels according to their manganese content. In the following, the various ranges of manganese compositions is surveyed.

AISI-SAE Wrought Carbon Steels

Carbon steels are used for a very broad range of applications; the tonnage produced annually far exceeds that of alloy steels. (Currently about 80 percent of domestic production is in carbon grades). Distinguishing among the various steels available is complicated by the fact that a variety of descriptive terms are used ranging from compositional designations to product shapes, manner of manufacture and other descriptions of quality. The most widely used systems for designating carbon steels in terms of their chemical compositions are those of the American Iron and Steel Institute (AISI) and the Society of Automotive Engineers (SAE). These systems are closely similar and carefully coordinated by the two groups. The designation is in the form of a numerical code that indicates the class of steel and, in particular, its approximate carbon content. The AISI-SAE system lists the steels

* See Nippon Steel News, May, 1982.

that are either produced in appreciable quantities or are used in significant quantities by at least two users. The absence of a composition from the list does not imply that it is unavailable.

When tabulated according to their code numbers, the standard carbon steels comprise four groups. The first is the 10xx series having a maximum of 1% Mn and also maxima levels of P (0.04%) and S (0.05%) with the carbon content shown by particular values of the digits xx. The carbon content ranges from $\leq$ 0.06 percent for a 1005 steel to a maximum of 1.03 percent for a 1095 steel. In general, the code does not directly indicate the manganese content which varies throughout the list. In some instances, however, a change in the numerical code indicates a change in the permissible manganese content without, necessarily, a change with respect to carbon: for example, the 1044, 1045, and 1046 steels all have carbon contents in the range of 0.43 percent to 0.5 percent, but have manganese ranges of 0.3 percent to 0.6 percent, 0.6 percent to 0.9 percent, and 0.7 percent to 1 percent, respectively. That steels differing by apparently minor variations in manganese contents warrant separate designations, probably reflects the potent effect of manganese on the hardenability of the steels, even though hardenability is not a major consideration with regard to many uses of carbon steel.

A summary of the ranges of manganese concentrations specified for this group is given in Table III.

The numerical code 15xx is used to identify a group of steels in which the manganese content can exceed 1 percent. Table IV presents the distribution of manganese ranges in this class. The last two designated groups of plain carbon steels are those in which the sulfur or the sulfur and phosphorus levels are increased to endow the steels with good machining characteristics. These are summarized in Table V.

Table III

AISI-SAE Designated Carbon Steels; 58 Types

Manganese Range, wt.%	Number of Steels
0.35 max.	1
0.25 to 0.40	1
0.25 to 0.45	1
0.25 to 0.50	1
0.25 to 0.60	10*
0.30 to 0.50	3
0.60 max.	1
0.30 to 0.60	8
0.50 to 0.80	3
0.60 to 0.90	21
0.70 to 1.00	8

*These ten steels are merchant quality; i.e., the least restrictive description for hot rolled bars used in non-critical parts. Source: A.S.M. Metals Handbook, 9th Edition.

Table IV

AISI-SAE Standard Carbon Steels With Maximum Mn > 1%

Manganese Range, wt.%	Number of Steels
0.75 to 1.05	1
0.80 to 1.10	1
0.85 to 1.15	2
1.00 to 1.30	1
1.05 to 1.40	1
1.10 to 1.40	4
1.20 to 1.50	2
1.20 to 1.55	3
1.30 to 1.65	2
1.35 to 1.65	3

Table V

AISI-SAE Sulfurized and Both
Resulfurized and Rephosphorized Steels

Manganese Range, wt.%	Number of Steels
0.30 to 0.60	1
0.60 to 0.90	1
0.70 to 1.00	5
0.75 to 1.05	1
0.85 to 1.15	1
1.00 to 1.30	1
1.30 to 1.60	1
1.35 to 1.65	4

The steels discussed so far do not have any specifications pertaining to hardenability. When a steel is designated to possess a specific hardenability, this is indicated in the AISI-SAE code by the addition of the letter H to the standard code. Inspection of the listed standard carbon H-steels shows that the manganese ranges of these steels are usually expanded in comparison with the corresponding unlettered steel. For example, a 1038 steel has a manganese range of 0.6 percent to 0.9 percent whereas the 1038 H steel can contain 0.5 to 1 percent manganese. On average, then, the manganese content in AISI-SAE carbon steels is not significantly affected by the hardenability designation per se.

AISI-SAE Standard Wrought Alloy Steels

For alloy steels the AISI-SAE codes distinguish two groups of steels; the first consists of standard steels while the second comprises experimental steels. These experimental steels have, as yet, been assigned no regular AISI-SAE designation. Some were developed to minimise the nickel content while others are modifications of a standard grade in order to improve some particular attribute of that grade.

Four of the standard grades contain manganese as the principal alloying element in addition to carbon while the rest contain additional elements. A summary of the manganese levels in standard alloy grades is presented in Table VI. As is also true for carbon steels the chemical specifications for the same grade of steel varies slightly according to product nature. Specifically, the ranges in plates are a little more generous than for bars, simply because compositional variations due to segregation are larger in the large rectangular ingots used in plate production than in the smaller ingots used for bars. For this reason, there are small variations in specified manganese ranges which do not necessarily imply a different grade of steel but instead merely enable the compositional specification to be met in practice. These variations generally decrease the lower limit of the range

Table VI

AISI-SAE Standard Wrought Alloy Steels

Manganese Range, wt.%	Number of Steels
0.25 to 0.45	3
0.30 to 0.50	1
0.40 to 0.60	3
0.45 to 0.65	7
0.50 to 0.70	2
0.60 to 0.80	2
0.65 to 0.85	1
0.70 to 0.90	33
0.70 to 0.95	2
0.75 to 1.00	30
1.60 to 1.90	4

while leaving the upper one unchanged. Accordingly, in Table VI the steels considered are those specified as bar products.

Unlike carbon steels, hardenability is often an important parameter and essentially all of the standard grades are also available with hardenability specifications. The impact on the manganese content is that the specified ranges are expanded compared to the standard grades to meet lower and higher hardenability specifications.

When the SAE experimental steels are compared with the standard grades it can be recognised that the general tendency is to specify somewhat more manganese, as is shown in Table VII.

High Strength Low Alloy Steels (HSLA)

In recent years a group of low alloy steels have become separately recognised and given the title high strength low alloy steels. These have been developed as a compromise between the convenient fabrication characteristics and the low cost of carbon steels and the high strengths attainable in heat treated alloy steels. They possess excellent strength and ductility in the as-rolled condition. In comparison with the majority of carbon and alloy steels, the HSLA steels contain greater manganese contents. The limits in the fourteen alloys designated by SAE range from 1 percent to 1.65 percent manganese.

ASTM Specified Steels

The most widely used specification for steel products are those published by the American Society for Testing Materials (ASTM). Steel products can be identified by the number of the ASTM specification. This number is arbitrarily serially assigned and is preceeded by the letter A for ferrous material. It is common practice to refer to a steel by the ASTM number specifying the product for which it is to be used.

Table VII

SAE Experimental Alloy Steels

Manganese Range, wt.%	Number of Steels
0.35 to 0.60	1
0.70 to 0.90	3
0.70 to 1.00	2
0.75 to 1.00	5
0.80 to 1.05	2
0.85 to 1.25	1
0.90 to 1.20	15
0.95 to 1.25	12

A number of the ASTM specifications incorporate an AISI-SAE number identifying the composition limits of the steel. However, many do not but instead impose their own compositional limits. The composition limits for manganese often merely comprise a maximum content and consequently offer no real indication of the actual content. It is a common feature of the ASTM specifications that the steel products are specified with respect to mechanical properties. Frequently, then, when the steel is produced to meet these requirements the composition ranges can only be regarded as a general indication. Within this context ASTM specifications for steel products cover the range from 0.1 percent maximum to 1.6 percent.

Ultra High Strength Steels

In addition to a number of the AISI-SAE standard alloy steels, which can be heat treated to high strength levels several other steels have been developed which are capable of attaining high strengths. These steels are usually highly alloyed with elements such as nickel, cobalt, and molybdenum so that manganese plays a relatively small role in their properties. Steels designated as maraging steels, for example, contain only 0.1 percent manganese. The term "maraging" derives from their specific response to heat treatment.

Stainless Steels

Stainless steels are ferrous alloys that are rich in chromium or chromium and nickel. Alloys composed principally of iron and chromium form the ferritic and martensitic classes of stainless steel while the austenitic stainless steels contain nickel as well as chromium. The family names of ferritic, martensitic and austenitic refer to structural characteristics of the principal constituent phase. All contain manganese but, unlike the case for standard carbon and alloy steels, SAE designations for stainless steels do not usually specify certain ranges for the manganese concentrations. Instead, the maximum manganese content is generally stated. These specifications are summarized in Table VIII.

Table VIII

Manganese Contents in Stainless Steels

Manganese Range, wt.%	Number of Steels
Austenitic Stainless Steels	
2.00 max.	22
5.50 to 7.50	1
7.50 to 10.0	1
14.5 to 16.5	1 (USS Tenelon)
Ferritic Stainless Steels	
1.00 max.	5
1.50 max.	1
1.25 max.	2
0.30 to 0.90	2
Martensitic Stainless Steels	
1.00 max.	9
1.25 max.	6

Source: "The Making, Shaping and Treatment of Steel," U. S. Steel Corp.

An interesting feature of the austenitic stainless steels are the three alloys quoted as possessing manganese concentrations rather larger than the usual levels. In part, this reflects the fact that an increase in manganese content permits a reduction in nickel content. In particular, USS Tenelon steel was developed following concern over nickel shortages that developed during World War Two and the Korean Conflict. Alone, manganese cannot be used to eliminate nickel completely; however, in combination with nitrogen, as in the Tenelon steel, success is achieved.

Cast Steel

Castings can be made from all the steel compositions so far described and in such cases the same discussion concerning manganese applies. As for wrought products, a collection of ASTM specifications have been established for cast steels. These frequently contain compositional specifications, sometimes in the form of ranges and other times as maxima values. Purchasers of castings frequently require certain mechanical properties to be satisfied. Accordingly, the precise composition is at the discretion of the supplier and hence published standard compositions should be regarded as guides. In general, cast steel products contain manganese in the range of 0.5 to 1.5 percent.

Cast Irons

Cast iron is a class of ferrous alloys based on the elements iron, carbon, and silicon where the carbon content is much greater than those of steel. The class comprises four groups called grey cast iron, ductile iron, malleable iron and alloy cast iron. All the various grades within each group contain manganese. Again, the compositions are variable such that overall concentrations can vary from .25 to 1.5 percent. Most commonly, the manganese contents are below 1 percent and, in that respect, are generally similar to the average case for plain carbon steels.

II. MANGANESE CONSUMPTION IN THE U.S. IRON AND STEEL INDUSTRY

A. Total Manganese Consumption

As previously noted, about 90 percent of manganese consumption in the U.S. is used in the manufacture of iron and steel products. The exact value is difficult to obtain because there are inputs of manganese to iron and steel manufacture and other processes that are not routinely summarized. Nevertheless, iron and steel production accounts for the bulk of manganese use and deserves special attention in view of the absence of manganese ores containing more than 35 percent manganese within the United States.

Manganese Consumption From Manganese Ores and Ferroalloys

Table IX presents total U.S. consumption of manganese in the form of manganese ores (> 35% Mn), ferroalloys, or metallic manganese for the years 1966 to 1981. The consumption in 1981 was approximately 1.15 million tons of manganese, most of which came from direct imports and shipments from government and industrial stockpiles. Definitions of manganese-bearing ores and ferroalloys are given in Tables X and XI. Government and industrial stockpiles have been primarily from imported sources because U.S. availability and production of manganese ores has been negligible for many years. On an annual basis, consumption does not equal the sum of direct imports and shipments from government stockpiles because of major changes in industrial stockpiles and, to a much lesser degree, exports and domestic sources. For the thirteen-year period, 1969-81, total manganese consumption was 17.038 million tons, the total of direct manganese imports was 13.410 million tons (7.885 in ore and 5.525 in ferroalloys), and the total of government stockpile shipments (almost entirely derived from foreign sources) was 3.379 million tons. Hence, the total of direct imports and government shipments for the period was 16.789 million

tons or 98.5 percent of consumption. In any given year, the percentage of consumption from these sources may differ markedly from the thirteen-year average; e.g., 83.7% in 1973 and 125.4% in 1975. Steel production rose dramatically in 1973 and dropped sharply in 1975. In general, industrial and government stockpiles are depleted during peak steel production years and rebuilt during years of low steel demand.

For the last five years there has been no production of ores containing more than 35 percent Mn. Small amounts of domestic ores containing about 10 percent Mn have been produced as shown in Table XII. Imports of manganese have been trending toward an increasing fraction of alloys. In 1981, about 70 percent of imported manganese was in the form of alloy, in contrast to 1969 when only 20 percent was in metallic form. Requirements of total manganese imports decline slightly with replacement of alloys for ores because most of the imported ore must be converted to ferroalloys for use in steelmaking. The conversion of ores to alloys in ferroalloy furnaces results in some loss of manganese to slags and other waste products. Currently, the recovery of manganese from ores in domestic ferroalloy production is about 80 to 90 percent. Total domestic production of manganese-bearing ferroalloys and silicomanganese is shown in Table XIII.

Table IX

U.S. Consumption of Manganese From Manganese Ores (>35% Mn) and Ferroalloys (Approximately 90% Used in the Manufacture of Iron and Steel), Imports of Manganese, and Shipments of Government Stockpile Excesses Expressed in Thousands of Short Tons of Contained Manganese.

Year	Consumption	Direct Imports(1)		Import Reliance, Percent	Shipments From Govt. Stockpiles	Government Stockpile, Percent(2)
		Ore	Alloy			
1981(estd)	1150	268	651	79.9	139	12.1
1980(estd)	1029	341	533	84.9	161	15.6
1979	1250	244	708	76.2	264	21.1
1978	1363	278	604	64.7	279	20.5
1977	1523	454	481	61.4	358	23.5
1976	1364	649	478	82.6	294	21.6
1975	1133	766	346	98.1	309	27.3
1974	1492	593	376	64.9	807	54.1
1973	1554	722	336	68.1	242	15.6
1972	1366	793	305	80.4	218	16.0
1971	1170	938	212	98.3	118	10.1
1970	1327	847	238	81.8	140	10.6
1969	1317	992	257	94.8	50	3.8
1968	1150					
1967	1207					
1966	1353					

(1) Imports other than those to government stockpiles. Imported ores contain 35-54% Mn. Imported alloys contain 74-95% Mn.

(2) Annual differences between consumption and the sum of imports and shipments from government stockpiles include shifts in industrial inventories and exports.

Source: U. S. Bureau of Mines, Bulletin 671, 1980
U. S. Bureau of Mines, "Manganese in 1981"
U. S. Bureau of Mines, "Manganese in May 1982"

Table X

Definition of Manganese-Bearing Ores*

Type	Description
Manganese Ore	Ores Containing More Than 35 Percent Mn.
Ferruginous Manganese Ore	Ores Containing From 10 to 35 Percent Mn.
Manganiferous Iron Ore	Ores Containing From 5 to 10 Percent Mn.
Iron Ores	Most North American Iron Ores Contain Small but Significant Amounts of Manganese. See Table XV.

*Based on U. S. Bureau of Mines classifications. The term ore includes concentrates, nodules, sinter, and synthetic materials for statistical purposes. Industrial and foreign classifications may differ from these manganese contents significantly.

Table XI

Brief Descriptions of Manganese-Bearing Ferroalloys and Metal[1]

Item	%Mn	%Si	%P	%C	%S
Standard Ferromanganese	74-82	<1.25	<0.35	<7.50	<0.05
Low-Phosphorous "	74-82	<1.25	<0.10	<7.50	<0.05
Low-Carbon "	80-90	<1.25	<0.35	<0.75	<0.05
Medium-Carbon "	80-85	<1.25	<0.35	<1.50	<0.05
Electrolytic Manganese	~99.9				
Silicomanganese	<75	18-20		<1.50	
Ferromanganese-Silicon	~65	~35		<0.08	
Spiegeleisen	16-28	1-5		<6.50	
Silicospiegel	25-30	7-8		2-3	

(1) These are general classifications only. Within each classification there may be several grades and a variety of special materials are marketed by producers. See ASTM Specifications A-99-76, A-483-64, A-701-74, A-98-64, A-601-69, and National Stockpile Specifications.

Sources: U. S. Bureau of Mines, Bulletin 671, 1980
U. S. Steel: "Making, Shaping, and Treating of Steels," 1971

Table XII

U.S. Shipments of Manganiferous Iron Ores

Year	Ferruginous Manganese Ore[1] Thousand Tons	Average %Mn	Contained Mn Thousand Tons
1981	-	-	-
1980	154.2	13.5	20.8
1979	214.7	13.5	29.0
	Manganiferous Iron Ore[2]		
1981	-	-	-
1980	19.7	9.5	1.9
1979	26.0	7.6	2.0

Source: G. L. DeHuff and T. S. Jones: "Manganese," Minerals Yearbook, U. S. Bureau of Mines, 1980.

(1) Primarily from Minnesota (~80%) and New Mexico (~20%).

(2) From South Carolina. Used primarily for coloring brick.

Table XIII

U. S. Production of Ferromanganese and Silicomanganese

Year	Ferromanganese[1] Thousands Tons	Silicomanganese[2] Thousands Tons
1981	-	-
1980	189.5	188.0
1979	317.1	165.0
1978	272.5	142.0
1977	334.1	120.0
1976	482.7	129.0

(1) Average Mn content ~ 80 percent

(2) Average Mn content ~ 20 percent

Source: U. S. Bureau of Mines, Minerals Yearbook, 1980
U. S. Bureau of Mines, Mineral Industry Surveys, "Manganese in 1981"
U. S. Bureau of Mines, Mineral Industry Surveys, "Manganese in May 1982"
(For current information contact Thomas S. Jones, (202) 634-7091)

U.S. production from domestic ores is shown in Table XIV. Specific information on the consumption of domestically produced and imported ferroalloys will be presented in a subsequent section of this chapter; however, it may be helpful to note here that per ton of raw molten steel produced approximately 12.6 pounds of manganese in the form of ferroalloys and 1.4 pounds of manganese in the form of manganese ores is used by the iron and steel industry.

Manganese Consumption From Iron Ores

In the opening paragraph of this chapter, it was noted that there are inputs of manganese to the steel industry that are not included in the statistics shown in Table IX. An obvious input is the manganese recycled in return and purchased iron and steel scrap. The importance of such manganese in recycled iron and steel scrap is shown and discussed in Chapters III and IV. However, here we are concerned primarily with the use of "virgin" or entry manganese. The iron and steel industry does derive a significant quantity of manganese from iron ores charged to blast furnaces. Table XV shows average manganese contents of U.S. and Canadian ore shipments from 1977-1981. Comparable figures should be available for imported iron ores (South American, African, etc.), because a premium is placed on the price of iron ore based on manganese content. The importance of this source can be estimated from the fact that U.S. consumption of iron ore (almost entirely in blast furnaces) was 111.9, 122.5, 126.8, 100.4, and 108.5 million tons in the years 1977 through 1981, respectively. At a representative manganese content of 0.3 percent, 100 million tons of iron ore contributes 0.3 million tons of manganese. Recovery of manganese during blast furnace ironmaking is about 75 percent. Hence, it is estimated that about 0.225 million tons of "virgin" manganese is made available to steelmaking through iron ores. This significant input (~20 percent of consumption) is not included in the statistics given in Table IX, but is included in subsequent technical and consumption forecasts in Chapters III and IV.

Table XIV

U.S. Production of Manganese Alloys From Domestic Raw Materials. Thousands of Tons of Manganese.

Year	Production
1981(1)	N/A
1980(1)	N/A
1979	31
1978	38
1977	27
1976	31
1975	19
1974	35
1973	31
1972	29
1971	38
1970	66
1969	93

(1) Recent U.S. Bureau of Mines publications exclude manganiferous ore containing less than 35 percent Mn. Apparently this accounts for about 2 percent of consumption.

Table XV

Brief Description of U.S. and Canada Iron Ore Shipments
1977 - 1981

Year		Millions Short Tons	Average %Fe	Average %Mn *
1981	U. S.	71.37	62.77	0.16
	Canada	49.95	63.59	0.36
1980	U. S.	68.53	62.53	0.18
	Canada	49.56	63.45	0.40
1979	U. S.	86.05	62.12	0.21
	Canada	60.00	63.32	0.39
1978	U. S.	82.61	61.87	0.26
	Canada	43.14	63.21	0.42
1977	U. S.	54.32	61.25	0.25
	Canada	54.47	62.65	0.40

Source: American Iron Ore Association, Iron Ore, A10A, Cleveland, Ohio, 1981

* The manganese content of U.S. pellets declined from an average of 0.17% in 1977 to 0.12% in 1981. Canadian pellets maintained a relatively constant manganese content of 0.50% during the same period.

B. Specific Manganese Consumption in the Iron and Steel Industry

Annual Manganese Consumption Data: 1962-81

As noted, most of the "virgin" manganese used in the iron and steel industry is added in the form of ferroalloys. Specific information for the years 1962 to 1980 is appended in a series of tables. Consumption in the iron and steel industry is presented by grade of steel produced and by type of manganese-bearing ferroalloy. The manganese consumption in ferroalloys was divided in 1980 between the different major types of ferroalloys about as follows:

Standard Ferromanganese	72.3%
Medium- and Low-Carbon Ferromanganese	13.5%
Silicomanganese	12.7%
Electrolytic Manganese	1.4%

In the appended tables, steel production data are divided into three principal grades which is consistent with the manner in which the American Iron and Steel Institute reports steel production data. The three principal grades are "carbon," "alloy," and "stainless and heat resistant." The relative share of each grade in domestic production for the years 1967 to 1981 is shown in Table XVI. The production share of carbon steels has declined from about 89 percent to 84 percent over the 15-year period. During the corresponding period, the shares of alloy and stainless steels have increased from about 10 percent to 14.5 percent and from about 1.1 percent to 1.5 percent, respectively.

Manganese consumption for the aggregated iron and steel industry is shown in Fig. 2 and Table XVII. During the nineteen-year period it remained very close to the average value of 13.94 pounds manganese per ton of raw steel and no significant trend is evident. For each year, two values are presented. The values on the left in Fig. 2 are calculated from manganese consumption and steel production

Table XVI

Trends in the Production of Raw Steel by Grades[3]

Year	% Carbon Steel*	% Alloy Steel*	% Stainless Steel*
1981	84.0	14.6	1.4
1980	84.7	13.8	1.5
1979	85.3	13.2	1.5
1978	85.3	13.3	1.4
1977	86.3	12.2	1.5
1976	87.5	11.2	1.3
1975	86.0	13.0	1.0
1974	86.9	11.6	1.5
1973	88.0	10.7	1.3
1972	88.3	10.5	1.2
1971	88.8	10.1	1.1
1970	89.3	9.7	1.0
1969	88.4	10.5	1.1
1968	88.4	10.5	1.1
1967	89.0	9.9	1.1

*Carbon steels contain less than 1.65 wt. percent manganese, 0.6 wt. percent silicon, and 0.6 wt. percent copper. They may contain small additions of other elements, notably boron or lead. Alloy steels may contain more manganese, silicon or copper, or they may have specified ranges for one or more other alloying elements.

Source: AISI Yearbook

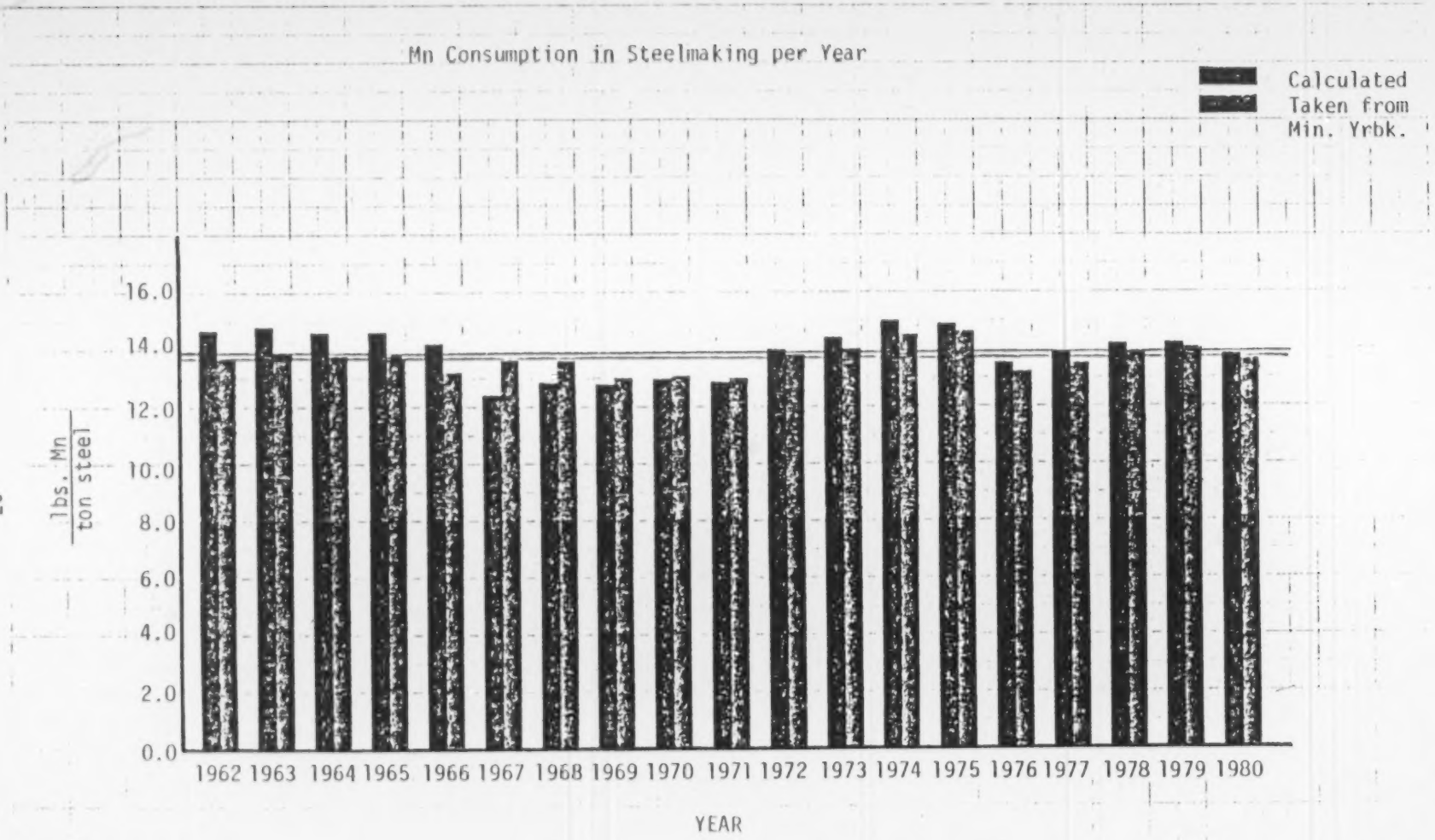

Figure 2. Manganese Consumption in the Aggregated Iron and Steel Industry. Includes Manganese From Ferroalloys and From Manganese Ore, but Not Manganese From Iron Ores and Recycled Scrap. Expressed as Pounds Manganese Per Ton of Raw Molten Steel Produced.

Table XVII

Manganese Consumption in the Aggregated Iron and Steel Industry. Includes Manganese From Ferroalloys and From Manganese Ore, but Not Manganese From Iron Ores and Recycled Scrap. Expressed as Pounds Manganese Per Ton of Raw Molten Steel Produced

YEAR	Mn CONSUMED	RAW STEEL PRODUCED	lbs. Mn / ton steel	OTHER NET.† Mn CONSUMED (tons)
1962	[illegible]	[illegible]	[illegible]	[illegible]
1963	[illegible]	[illegible]	[illegible]	[illegible]
1964	[illegible]	[illegible]	[illegible]	[illegible]
1965	[illegible]	[illegible]	[illegible]	[illegible]
1966	[illegible]	[illegible]	[illegible]	[illegible]
1967	[illegible]	[illegible]	[illegible]	[illegible]
1968	[illegible]	[illegible]	[illegible]	[illegible]
1969	[illegible]	[illegible]	[illegible]	[illegible]
1970	[illegible]	[illegible]	13.30 [illegible]	[illegible]
1971	[illegible]	[illegible]	[illegible]	[illegible]
1972	[illegible]	[illegible]	[illegible]	[illegible]
1973	[illegible]	[illegible]	[illegible]	[illegible]
1974	[illegible]	[illegible]	[illegible]	[illegible]
1975	[illegible]	[illegible]	[illegible]	[illegible]
1976	[illegible]	[illegible]	[illegible]	[illegible]
1977	[illegible]	[illegible]	[illegible]	[illegible]
1978	[illegible]	[illegible]	[illegible]	[illegible]
1979	[illegible]	[illegible]	[illegible]	[illegible]
1980	[illegible]	[illegible]	[illegible]	[illegible]
Average	[illegible]		13.[illegible] *	

*Numbers in parenthesis taken from USBM Minerals yearbooks.

†Includes all consumption of manganese other than that in steel production.

statistics. The values on the right are those reported by the U. S. Bureau of Mines in Mineral Yearbooks. The discrepancies are minor. It is important to reemphasize that these data do not include manganese consumption from iron ores and recycled scrap. Also, the data are summarized in terms of manganese consumption per ton of raw molten steel and not in terms of tonnage of steel product shipments. Consumption expressed on the basis of product tonnage currently is about 33 percent greater than that expressed on the basis of raw steel tonnage because the yield of products from raw steel is currently about 75 percent. The importance of yield in manganese consumption is discussed in the following two chapters.

Manganese Consumption in Different Grades of Steel

Manganese consumption by grade of steel is shown in Fig. 3 and Table XVIII on the same basis as in Fig. 2 and Table XVII. For the fourteen-year period (1967-1980) the average manganese consumptions in the production of the three primary grades of steel were the following:

Carbon Steels	11.67 lbs./ton
Alloy Steels	21.09 lbs./ton
Stainless Steels	22.88 lbs./ton

As noted, the weighted average for all three grades was 13.94 pounds per ton of raw molten steel. No significant trend in the consumption of manganese in carbon steels is evident. Slightly higher than average manganese consumption in alloy steels is shown for the period from 1971 to 1976. The reason for this is not clear and a much more detailed analysis of the product mix and processing data would be required to develop an explanation. Manganese consumption in stainless steels shows a decline during the period from 1970 through 1977. It is believed that this decline is primarily the result of the adoption of the AOD process (Argon-Oxygen Decarburization) as a refining method in stainless steel production. The

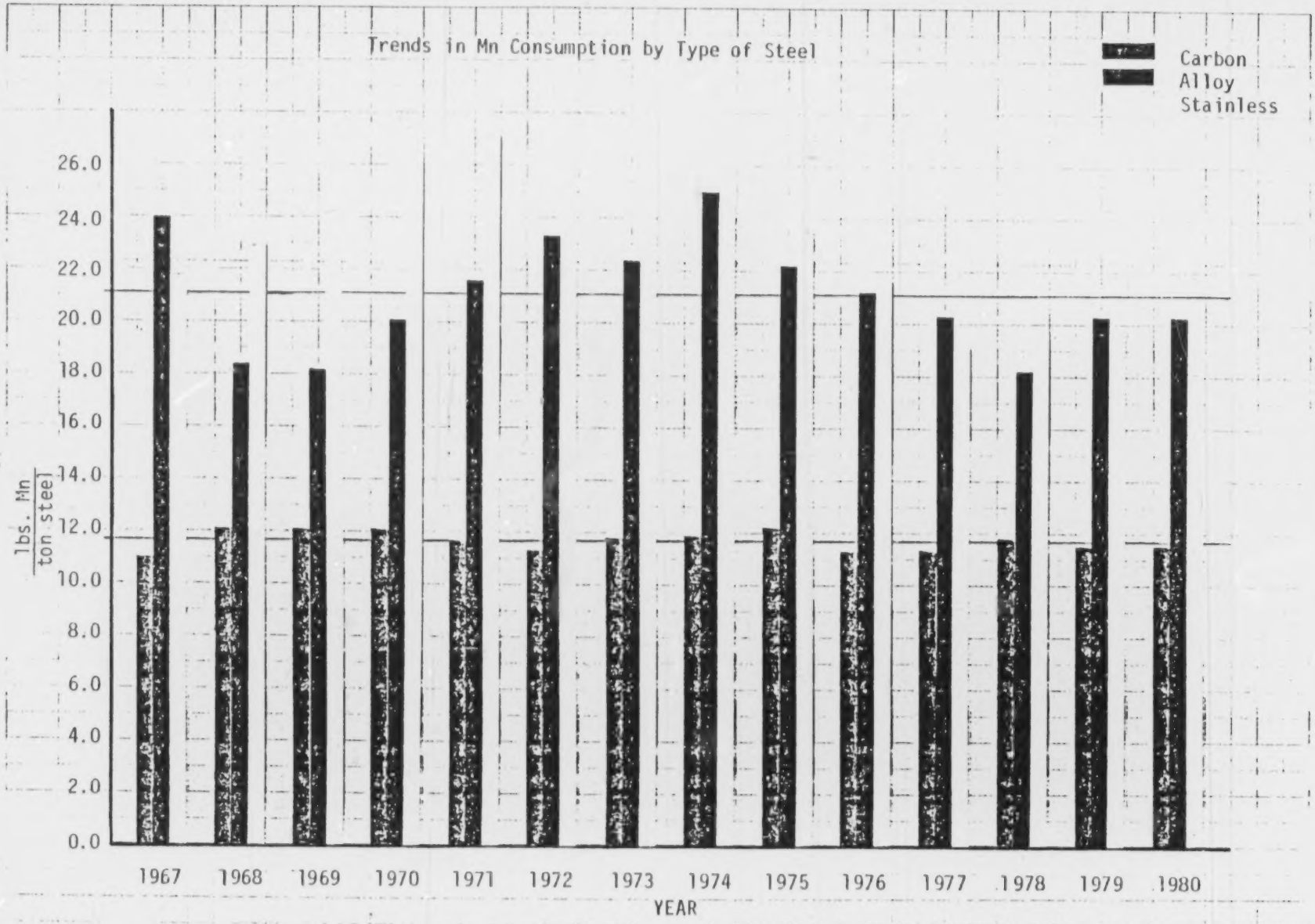

Figure 3. Manganese Consumption by Steel Grades. From Manganese Ores and Ferroalloys. Expressed as Pounds of Manganese Per Ton Raw Molten Steel.

Table XVIII

Manganese Consumption by Steel Grades. From Manganese Ores and Ferroalloys (1967-71) and Ferroalloys Only (1972-80). Expressed as Pounds of Manganese Per Ton Raw Molten Steel.

Year	Grade	Mn Used in Steel (1000 tons)	Domestic Raw Steel Produced (1000 tons)	Lbs. Mn per ton steel
1967	Carbon	425,035	113,199	11.94
	Alloy	150,824	12,572	23.96
	Stainless	1,443	1,451	21.82
1968	Carbon	20[illegible],004	116,284	13.14
	Alloy	[illegible],124	13,761	19.38
	Stainless	1,423	1,432	22.94
1969	Carbon	[illegible],349	124,832	12.93
	Alloy	131,994	11,861	18.17
	Stainless	18,417	1,569	24.16
1970	Carbon	208,913	117,411	10.09
	Alloy	[illegible],448	12,824	20.12
	Stainless	1,[illegible]39	1,279	23.44
1971	Carbon	41,[illegible]98	107,067	11.08
	Alloy	[illegible],218	12,173	24.56
	Stainless	17,[illegible]23	1,283	27.07
1972	Carbon	468,178	117,698	11.27
	Alloy	143,022	13,979	23.42
	Stainless	19,[illegible]13	1,564	24.96
1973	Carbon	[illegible],[illegible]36	132,747	11.77
	Alloy	[illegible],[illegible]79	16,183	20.69
	Stainless	[illegible],[illegible]92	1,887	25.15
1974	Carbon	459,253	126,609	11.23
	Alloy	17,[illegible]37	16,962	25.00
	Stainless	2[illegible],[illegible]24	2,150	24.67
1975	Carbon	410,[illegible]73	100,360	12.17
	Alloy	150,846	15,171	22.17
	Stainless	18,[illegible]73	1,111	33.38
1976	Carbon	440,069	112,008	11.[illegible]
	Alloy	151,[illegible]08	14,303	21.[illegible]
	Stainless	19,[illegible]75	1,681	23.[illegible]
1977	Carbon	413,147	108,130	11.42
	Alloy	150,671	15,341	19.[illegible]
	Stainless	17,[illegible]09	1,882	19.13
1978	Carbon	486,462	114,916	11.80
	Alloy	144,[illegible]73	18,161	18.16
	Stainless	18,[illegible]16	1,954	19.[illegible]
1979	Carbon	468,[illegible]39	116,226	11.[illegible]
	Alloy	182,[illegible]93	18,906	20.[illegible]
	Stainless	[illegible],[illegible]46	2,107	19.90
1980	Carbon	[illegible],[illegible]70	94,689	11.[illegible]
	Alloy	[illegible],[illegible]64	15,145	[illegible].[illegible]
	Stainless	17,[illegible]30	1,201	18.[illegible]

Average [illegible] for each grade

Carbon - 11.5
Alloy - [illegible].09

AOD process is operated in conjunction with electric arc furnace melting and the recovery of oxidizable elements, particularly chromium but also manganese, is substantially enhanced by this method. Care must be taken to recall that most steel production falls in the carbon grades (Table XVI). Therefore, the current share of each steel grade in manganese consumption is about as follows.

Carbon Steels	75%
Alloy Steels	23%
Stainless Steels	2%

Also, the data of Fig. 2 and Table XVII show that there has been no significant change in manganese consumption per ton of aggregated raw steel production during the period from 1962 to 1981. Therefore, there is no basis for predicting a significant change in the manganese requirements per ton of raw molten steel from the aggregated retrospective data. However, bases do exist for predicting significant reductions in manganese requirements per ton of raw steel and, more importantly, per ton of steel products through the year 2000. The rationale for these reductions rests primarily in the areas of increased yield of steel products from blast furnace iron and scrap, and increased recovery of manganese in primary and secondary steelmaking. To a lesser and much more uncertain extent, changes in product mix and specifications will influence manganese consumption. These and related technological factors will be discussed in the next two chapters.

III. TECHNOLOGICAL DEVELOPMENTS

Technological developments will be discussed in terms of the primary factors involved in forecasting manganese use. In order to make a general forecast of the consumption of manganese in iron and steel production, it is first necessary to make a forecast of the required manganese per ton of raw steel. For convenience we will use the units of pounds of manganese required per ton of raw steel. The total annual manganese requirement for the U.S. industry is then given by Eq. (1).

$$\left(\frac{\text{Lbs. Mn Rqd.}}{\text{Year}}\right) = \left(\frac{\text{Lbs. Mn Specd.}}{\text{Ton Raw Steel}}\right)\left(\frac{\text{Lbs. Mn Rqd.}}{\text{Lb. Mn Specd.}}\right)\left(\frac{\text{Tons Raw Steel}}{\text{Ton Product}}\right)\left(\frac{\text{Tons Product}}{\text{Year}}\right) \quad . \quad (1)$$

The first term on the r.h.s. of Eq. (1), pounds Mn specified per ton of raw steel, is determined by the mix of carbon, alloy, and stainless steel production and by compositional requirements specified for these steels by steel users. The second term on the r.h.s. is determined by the efficiency with which the manganese content of ore, scrap, pig iron, and ferroalloys are retained during steelmaking and other metallurgical factors such as recovery of manganese during handling and addition of ferroalloys and recovery of manganese from waste products. The third term on the r.h.s. of Eq. (1), tons of raw steel required per ton of steel product, is determined by the efficiency with which raw molten steel is converted into primary steel products within the steel industry. It is the reciprocal of yield. As yield improves, manganese requirements decline. It has been noted in earlier sections that greater use of continuous casting results in marked improvement in yield. Other processing developments such as direct rolling of hot slabs and billets from the caster can improve yield. Product mix affects yield also. In general, yield is lowest in the production of items such as small gauge sheets, wire, and tubing and greatest in the production of plates and rods. The fourth term on the r.h.s.

of Eq. (1), tons of domestic product required per year, is determined by the state of the U.S. economy, steel imports, and other complex factors. The demand for steel products has fluctuated drastically in recent years. During 1982, the U.S. demand for steel declined to its lowest value in the last four decades. During the period from 1950 to 1980, the relative importance of U.S. steel production in the GNP decreased by a factor of two.[5] Most analysts have concluded that the demand for steel in the U.S. will grow at a modest rate for the next decade, and, probably, through the year 2000. An annual growth rate of 1.4 percent for U.S. steel demand has been assumed by the Bureau of Mines[1,4] and NMAB.[2] Based on a trend line value of 93.7 million tons of U.S. steel industry shipments in 1978 (actual shipments were 97.94 million), an annual growth rate of 1.4 percent, and an assumption that the import share does not change markedly, the projected values of annual U.S. produced steel products in 1990 and 2000 are 115.7 and 133.0 million tons, respectively. These production projections are only 3.9 percent and 19.4 percent greater, respectively, than the peak year of 1973 when the U.S. steel industry shipped 111.4 million tons of product.

In the ensuing sections of this chapter, current technological and metallurgical trends and possible developments during the next two decades will be discussed. It should be noted that these technological changes are expected to influence manganese requirements primarily either by altering the amount of manganese that must be added to raw molten steel or by altering the yield with which raw molten steel is converted to steel products. To a lesser, and more unpredictable extent, technological changes might influence manganese requirements by improvement of the competitive position of the domestic steel industry and a resultant increase in the demand for U.S. steel products both by a reduction of imports and an increase in exports. Consideration of the latter aspects are outside the objective of the present study.

Therefore, the following sections are presented in terms of developments that should alter the required amount of manganese per ton of raw steel produced and developments that should alter yield of product from raw steel.

A. Raw Material Developments

The most significant development in raw materials during the past few years has been the shift of imports from manganese ore to ferromanganese alloys (see Table IX). As noted earlier, the steel industry uses manganese primarily in ferroalloy form. Hence, imported manganese ore must be converted to ferromanganese products in domestic ferroalloy plants. During the conversion, approximately 10 to 20 percent of the contained manganese in the ore is lost to slag and other waste. Hence, the trend toward imported ferromanganese lowers manganese consumption at receiving ports. However, most of the government stockpiles and a great fraction of industrial stockpiles is in the form of manganese ore and it will be necessary to maintain ferromanganese production capacity if these materials are to be used domestically. Recently, domestic manganese ferroalloy plants have been acquired by foreign firms; e.g., Norwegian and Canadian.(9)

The only significant direct use of manganese ore in the steel industry is in the iron blast furnace where it is desirable to produce hot metal with a significant manganese content usually more than 0.6%. Approximately 25 percent of the manganese charged to iron blast furnaces is lost to slag.

Currently, there are no satisfactory methods for recovering manganese from iron and steelmaking slags, dusts, sludges, scales, and other wastes other than to include as much as possible of these materials in the charge to sinter strands. Sinter strands produce an iron oxide agglomerate which can be charged to blast furnaces for hot metal production. There are no reliable data on the extent to which manganese is recovered in these waste materials. No blast furnace slag is

recycled in this manner but it does find other commercial uses in the brick, aggregate, glass, and bedding industries. It is safe to say that less than 20 percent of the manganese contained in iron and steel industry waste materials is currently recovered for reuse. This does not include iron and steel scrap which is not classified as waste because of the ease with which it may be recycled. Based on the great effort that has been devoted to waste manganese recovery for many years, it is unlikely that a commercially acceptable scheme will be developed in the next two decades. Only national emergency conditions or an unlikely drastic rise in the price of World manganese would alter the situation.

A significant fraction of the manganese input to ironmaking comes from iron ores (~0.3% Mn) as distinct from manganese ores. The trend in recent years has been a decline in the average manganese content of U.S. and Canadian iron ores. (See Table XV). This trend, if continued, might necessitate the use of increasing amounts of manganese-bearing ore in blast furnaces.*

Direct reduction processes are not expected to make a major impact on the domestic steel industry during the next few years because of the absence of inexpensive natural gas and the slowness of the development of suitable coal-based direct reduction processes. However, the availability of D.R.I. on the World market may assume importance. Where D.R.I. is substituted for scrap in steel production, there is a need to make up the difference in manganese content. In general, D.R.I. contains much less recoverable manganese than does scrap.

B. Processing Developments

Processing developments are divided into the general areas of ironmaking (primarily to produce raw iron for steelmaking), external desulphurization and pretreatment of hot metal, primary steelmaking, ladle and secondary steel refining, continuous casting, and forming.

*Taconite ores used in U.S. pellet production have a low manganese content; however, it should be possible to blend some higher manganese containing ore concentrates with the taconite concentrates prior to pelletization.

Ironmaking

Although construction and operation of direct reduction plants will continue in certain parts of the world, e.g., Mid East, Mexico, South America, USSR, etc., where natural gas is abundant, the principal source of domestic crude iron will continue to be the blast furnace. Over the next few years, the trend to shut down the oldest and least efficient blast furnaces and to upgrade the better furnaces will continue. Furnaces are upgraded in a number of ways including charging system modifications, improved relining configurations, hot blast and additive improvements, pressurization, tapping procedures, and general instrumentation and control techniques. All of these developments taken as a whole increase the productivity (tons/day) and reduce fuel and energy requirements per ton of hot metal produced. It is unlikely that these developments will have a major effect on manganese utilization. While it may be possible to operate blast furnaces with somewhat more acid burdens (less lime, more silica) as external desulphurization removes the requirement for basic slags to desulphurize in the blast furnace, the manganese recovery in the hot metal tends to decrease with such changes. It is expected that manganese recovery in hot metal will decrease somewhat from its current value of 75 percent. This should be offset by the opportunity to include more manganese-bearing steelmaking slag (primarily for iron, lime, and flux content, but secondarily, for manganese) in the blast furnace charge.*

Hot metal used in basic oxygen steelmaking furnaces is rated according to its temperature and contents of carbon, silicon, manganese, phosphorous, and sulphur. In general, the manganese content of hot metal is important from two standpoints. Firstly, the higher the manganese content in the metallic charge, the higher is the residual manganese content of the raw molten steel after oxidation refining. Secondly, the manganese that is oxidized during the initial period of oxygen steelmaking is incorporated in the steelmaking slag. The presence of MnO in the slag helps

*The extent to which steelmaking slag can be recycled in the blast furnace is limited, in part, by phosphorous content.

to develop proper slag characteristics, in part through more rapid dissolution of lime. If the manganese content of the hot metal is too low, additional slag fluxes containing fluorspar must be used. In some plants, it is desired to maintain the manganese content of hot metal above about 0.6 percent; however, this depends upon many other factors including the carbon content of the steel being produced. For high-carbon-steel heats, early slag formation is more critical and, therefore, a higher manganese content in the hot metal is more desirable.

External Desulphurization

The desulphurization of hot metal prior to its introduction to basic oxygen steelmaking units will become almost universal in the domestic industry by 1990. This will relieve the function of desulphurization in steelmaking and lead to much loser residual sulphur levels in new steel and, eventually, in recycled steel scrap. Indirectly, this affects manganese issues by reducing manganese requirements intended solely for control of sulphides in finished steel. However, the function of manganese in steels is more than that associated with sulphide control.

Steelmaking

The basic oxygen processes are undergoing dramatic changes with the incorporation of bottom blowing and inert gas mixing techniques. These improvements result in much greater recovery of manganese in steelmaking (e.g., see Figure 4). Currently, manganese recovery in oxygen steelmaking ranges from 20 to 50 percent depending upon final carbon content (the higher the carbon content, the higher the residual Mn) and temperature (again, higher finishing temperatures are better as far as manganese recovery is concerned). It is expected that manganese recovery will increase into the range of values from 40 to 60 percent over the next few years as a result of these and other changes (including separate desiliconization and better charge and slag control.) Furthermore, manganese recovery in electric arc furnaces is substantially better than that in oxygen steelmaking furnaces and the production share of the EAF is expected to continue its upward trend.

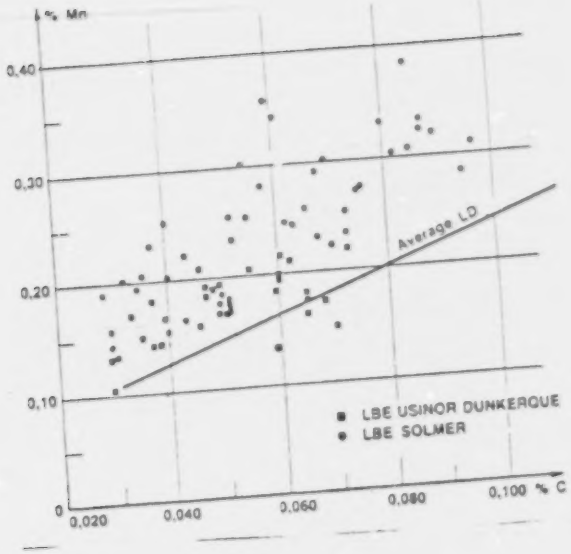

Figure 4. Improvements in Manganese Recovery in BOP Steelmaking From Bottom Blowing and Inert Gas Mixing. Residual % Mn Versus Final % C. LD Refers to "Standard" Top Blown Oxygen Steelmaking While LBE Refers to the Inclusion of Inert Gas Injection Through Permeable Refractory Elements.

Source: P. Gugliermina, R. Lecigne, and J. C. Grosjean, Iron and Steelmaker, July, 1982, p. 38.

Manganese recovery in electric arc furnaces is expected to improve somewhat over the next few years as a result of better charge materials, reduced oxidation during high speed meltdown, improved end-point control, and greater use of secondary and ladle refining.

Ladle and Secondary Refining

As noted earlier, the role of ladle and secondary refining has grown rapidly during the past few years. In stainless steel production, adoption of the AOD process and modifications thereof is almost universal. For low alloy and carbon grades, deoxidation and desulphurization procedures have been greatly improved along with increased use of argon shrouding of steel surfaces and pouring streams. All of these developments reduce manganese requirements in several ways. Firstly, melt protection (along with better sensing, analytical, and control instrumentation) allows for elimination of excessive use of manganese. In the industry this is sometimes called "trimming." The manganese content of added ferroalloys is captured in the steel to a much higher degree and there is much less reoxidation loss during subsequent pouring. Once again, the desulphurization (by injected lime, calcium, rare earths, etc.) reduces the sulphur content to levels below 0.01 percent and often below 0.005 percent. As a result, the manganese required for sulphide control in finished steel is greatly diminished.

Continuous Casting

The benefits of continuous casting have been fully established. In addition to overall cost savings, continuous casting leads to much greater yields of steel products from raw molten steel, improved quality (cleanliness, homogeneity), reduction of energy requirements and metal loss (scaling) during ingot reheating, and a host of other benefits. From the manganese standpoint, increased yield means that less home scrap must be recycled. When scrap is recycled, there is always substantial manganese loss to slags and dusts. Also, there is less scaling

loss. Currently, about 25 percent of domestic steel is continuously cast. By the end of 1984, 50 percent should be continuously cast. By the year-2000, it is likely that about 70 percent of domestic steel will be cast continuously. During 1981, 70.7 percent of steel was continuously cast in Japan.[8]

Forming

Direct rolling of hot slabs and billets from continuous casters has been demonstrated in several plants throughout the world. Widespread adoption depends, in part, upon the development and use of good surface quality on-line control sensors. The elimination of the cooling and reheating steps reduces metal loss as well as saving energy. Another important development that may influence manganese requirements in strip products is continuous annealing. Some steel-plant metallurgists have indicated that microstructural features of continuously annealed products may be enhanced by some reduction in manganese content provided, of course, that the sulphur contents are reduced to very low levels. A preliminary, and perhaps unrelated, observation is that reduction of manganese contents in these products may be limited by some tendency for surface cracks to form during the first bend of continuously cast slabs.

C. Alloy Developments

The following list identifies several examples of relatively recent technological developments which have the potential of affecting manganese consumption. The list is not exhaustive but should serve to illustrate some developments which are considered to be important.

High-Strength Low-Alloy Steels

A special category of plain carbon steels characterized by higher strength than plain carbon structural steels has become increasingly popular over the past decade. The demand for these steels, referred to generically as High-Strength Low-Alloy or Higher-Strength Low-Alloy (HSLA), derives in large part from the transportation industry where their use affords weight reduction (improving fuel

economy) without sacrificing structural integrity. They are also being used now in a variety of other applications.

The HSLA steels are produced to specifications which identify yield and tensile strength requirements. Typically, the range of yield strengths available in various HSLA grades are from 40,000 psi to 80,000 psi which should be compared to 30,000 psi to 45,000 psi yield strengths of the commonly available standard plain carbon grades. The strength of many of the HSLA steels derives principally from manganese in the rather substantial amounts of 1.00 to 1.65 wt. percent. In some grades, the manganese increases strength by solid solution strengthening. In others, manganese contributes to strength increases via hardenability with the result that the steel contains both strong martensite and soft ferrite. These latter grades are called dual-phase steels. The HSLA steels have, as an added benefit, improved atmospheric corrosion resistance. In some grades the manganese content is reduced to levels of 0.65 to 1.00 wt. percent while strength is maintained through very small additions of niobium, zirconium, titanium and molybdenum. In summary, it is important to note that a significant class of steels, including those referred to as microalloy steels, now exists which specifically derive their distinct properties from a higher than average manganese content. These steels should be subject to increasing demand as economic factors, such as petroleum costs, favor higher strength-to-weight ratios in structural materials. The share of alloy steel in U.S. production rose from 9.9 to 14.6% between 1967 and 1981 (Table XVI). See page 54 and page 66 for forecasts.

Continuous Annealing

Implementation of improved processing techniques may, in some instances, influence the alloy content of the steel products being produced. Continuous annealing is an example of technology improvement that could exert significant pressure towards reducing manganese contents in steel plate and sheet. The reason derives from the fact that nearly all flat-rolled products are annealed after rolling, a process which involves heating the steel at temperatures and times sufficient to complete the recrystallization process. It is common practice to anneal coils of

steel sheet and strip in batches (box anneal) for times dependent upon the size of the coil, but it may take several hours. Because the inside of a coil will have experienced a different thermal cycle than the outer layers, some nonuniformity in properties over the length of the strip in a coil is unavoidable.

Continuous annealing, as the name implies, involves annealing of the strip as it comes from the roll stands and before it is coiled. Some of the advantages offered by continuous annealing over box annealing include uniformity of properties, higher strength, better control over surface cleanliness (important for reasons of paintability) and improved control over flatness. During continuous annealing the steel spends considerably less time in the furnace than in the case of box annealing. Therefore, the time necessary to accomplish recrystallization during the anneal becomes of critical importance in determining the rate of production. Manganese acts to slow the recrystallization process and, because of this, there is a distinct trend to reduce the manganese contents of steel strip as plants convert from box to continuous anneal.

Alloy Substitutions

Each of the major alloying elements commonly added to steel generally has its own unique function, but in some instances the effects offered by two elements may be sufficiently similar that one can be successfully substituted for the other. Manganese and nickel are sufficiently alike in this regard, and like manganese, nickel is a strategic material for which the U.S. must rely upon imports. Nickel is a common addition to alloy steels and is important in producing stainless steels (in conjunction with chromium), very tough steels for service at cryogenic temperatures, and a number of specialty grades such as maraging steels. The prospects for substituting manganese for nickel has been the subject of some research initiated particularly by the nickel shortages which occurred during World War II and the Korean Conflict. In some cases, it has been shown that manganese can

successfully replace nickel if other changes in chemistry are also made. Thus, nickel shortages, if they occur again, could indeed cause added pressure on manganese consumption. It should be noted, however, that the alloy steels which consume significant quantities of nickel constitute a small fraction of the overall tonnage of steel produced in the U. S. (Table XVI)

Overall Impact

As shown in Table XVI, the trend in domestic steel production over the past two decades has been for an increasing share of steel production in alloy and stainless grades. This trend is expected to continue to the end of the century and it is likely that the carbon steel share will decline to about 80 percent while the alloy steel and stainless steel shares will increase to 18 percent and 2 percent, respectively.* Based on the greater manganese requirements in the alloy grades (Figure 3), this trend alone leads to a positive force on manganese requirements. However, it is expected that manganese requirements in carbon steels will decline somewhat as a result of lowered sulphur burdens. A primary function of manganese in carbon steels is sulphide control. The decreased requirement of manganese in carbon steels should more than offset the increasing share of alloy steels. Furthermore, processing advances as discussed previously and in the chapter on forecasting to follow are expected to bring substantial manganese savings over the next two decades.

*Clearly, such projections are subject to error. It is intrinsically better to forecast the demand for each grade on an absolute basis and then compute percentages rather than to forecast percentages in this simple manner. However, the historical data in Table XVIII indicate that the demand for alloy and stainless steel rise and fall in proportion with the demand for carbon steel, subject only to a gradual trend in favor of alloy steel. Only drastic changes in the balance of economic activity could shift the shares to 70% carbon, 27% alloy, and 3% stainless or to 90% carbon, 9% alloy, and 1% stainless. A drastic shift in favor of alloy steels might arise from severe reduction in new construction and manufacture of machinery, vehicles, and containers, with a corresponding (or relative gain) in construction of new chemical, petrochemical, coal conversion, and power plants. Similarly, a drastic shift away from the trendline in favor of carbon steels might arise from abnormal demand for new buildings, highways, vehicles, and primary machinery.

IV. FORECAST AND SUMMARY

As noted in the previous chapters, there are four principal ways in which total manganese requirements in iron and steel production can be reduced.

- Increased efficiency in the recovery and retainment of manganese during iron and steelmaking.
- Decreased specifications for manganese contents in iron and steel products.
- Increased efficiency in the conversion of raw molten steel into steel products (yield).
- Decreased demand for domestically produced iron and steel products.

The last item is based on complex economic and political factors throughout the World as well as the specific conditions within the U. S. steel industry and governmental policies affecting the U. S. industry. Certainly, it is hoped that the domestic steel industry will regain its former strength and vitality and that the demand for domestically produced steel will increase substantially from presently depressed levels. Forecasts in this area are outside of the objectives of this study. Hence, the discussion centers on manganese requirements per ton of domestically produced steel products.

A. Forecast

Tables XIX and XX and Figure 5 present summary information and calculations on the current use of manganese in the aggregated steel industry. The resultant figures indicate that the use of manganese from ferroalloys corresponds to about 12.20 pounds per ton raw molten steel and to about 16.26 pounds per ton of steel products. For comparison, another set of values has been calculated based on the conditions summarized in Table XXI. Here it has been assumed that the average specified content of Mn in steel products is decreased from a value of 0.7 percent to a value of 0.62 percent based on assumed changes in the composition and mix of

Table XIX

Current Manganese Inputs/Outputs in Steel Production: Conditions Assumed in Construction of Figure 5 and Table XX

1. In the blast furnace, 75 percent of charged manganese (primarily in iron ore and manganese ore) is recovered in hot metal.

2. The metallic charge to steelmaking consists of 50 percent hot metal containing 0.7 percent Mn and 50 percent home and purchased scrap containing 0.63 percent Mn.(1)

3. The yield of raw steel from steelmaking is 85 percent of charge hot metal and scrap.

4. Of the metallic loss in steelmaking (difference between hot metal plus scrap and raw steel), 50 percent is home scrap and 50 percent is lost to slag and dust.

5. The finishing manganese content in the raw steel after steelmaking is 0.2 percent. This corresponds to 26 percent recovery of charge manganese.

6. In ladle/secondary refining, 18 percent of the manganese in added ferroalloys is lost in waste.

7. The yield of steel products from raw steel is 75 percent.

8. Of the metallic loss in casting/finishing, 90 percent is home scrap and 10 percent is waste.

(1) This is equivalent to ~ 72 percent steel production in BOP (and open hearth) and ~ 28 percent in EAF.

Note also that the current average manganese content of hot metal is assumed to be 0.7 percent. If, in fact, this figure is greater than 0.7 percent, then the amount of manganese charged with ore and sinter to the blast furnace must be increased accordingly but the manganese ore consumption is not altered because it is known from USBM consumption data.

Note also that the average Mn content of the charge scrap is 0.63% based on 53% home scrap containing 0.56% Mn and 47% purchased scrap at 0.70% Mn.

Figure 5. Current Representation of Manganese Inputs and Outputs in the Production of One Ton of Steel Products. All Numbers Are Expressed in Pounds of Manganese. See Table XIX for Additional Conditions.

Blast Furnace		Steelmaking		Ladle/Secondary Refining		Casting/Finishing	
In		**In**		**In**		**In**	
Iron Ore, Sinter[1]	12.77	Hot Metal (0.784t@0.7%Mn)	10.98	Raw Steel (1.333t@0.2%Mn)	5.33	Refd. Steel (1.333t@0.7%Mn)	18.66
Manganese Ore[2]	1.87	Home Scrap (0.418t@0.56%Mn)	4.67	Ferroalloys	16.26		
		Purchased Scrap (0.366t@0.7%Mn)	5.12				
	14.64		20.77		21.59		18.66
Out		**Out**		**Out**		**Out**	
Hot Metal[3] (0.784t@0.7%Mn)	10.98	Raw Steel (1.333t@0.2%Mn)	5.33	Refd. Steel (1.333t@0.7%Mn)	18.66	Steel Products (1.000t@0.7%Mn)	14.00
Slag	3.66	Home Scrap (0.118t@0.2%Mn)	0.47	Waste	2.93	Home Scrap (0.300t@0.7%Mn)	4.20
		Slag and Dust	14.97			Waste	0.46
	14.64		20.77		21.59		18.66

Notes:

(1) Approximately 1.189 tons iron ore, sinter, and slag (containing ~ 62% Fe and ~ 0.54% Mn). Note that this results in 0.61% Mn in hot metal based on 75% recovery of Mn. The remaining 0.09% Mn in hot metal is derived from manganese ore.

(2) Based on USBM Consumption Data.

(3) Average Mn content of hot metal is estimated. It may be greater if manganese content of iron ore/sinter is greater.

Table XX

Summary of Current Representation of Manganese Inputs and Outputs in the Production of One Ton of Steel Products

Inputs of Manganese, Pounds		
Blast Furnace Iron Ore, Sinter*		12.77
Blast Furnace Manganese Ore*		1.87
Purchased Scrap (0.366t@0.7%Mn)		5.12
Ferroalloys		16.26
	Total	36.02
Outputs of Manganese, Pounds		
Steel Products (1.000t@0.7%Mn)		14.00
Losses		
Blast Furnace Slag*		3.66
Steelmaking Slag, Dust		14.97
Ladle/Secondary Refining Waste		2.93
Casting/Finishing Waste		0.46
	Total	36.02

*See footnotes to Figure 5.

Table XXI

Projected (Year-2000) Manganese Inputs/Outputs in Steel Production: Conditions Assumed in Construction of Figure 6 and Table XXII

1. In the blast furnace, 75 percent of charged manganese (primarily in ore) is recovered in hot metal.

2. The metallic charge to steelmaking consists of 40 percent hot metal containing 0.7 percent Mn and 60 percent home and purchased scrap containing 0.59 percent Mn.

3. The yield of raw steel from steelmaking is 90 percent of charge hot metal and scrap.

4. Of the metallic loss in steelmaking (difference between hot metal plus scrap and raw steel), 50 percent is home scrap and 50 percent is lost to slag and dust.

5. The finishing manganese content in the raw steel after steelmaking is 0.3 percent. This corresponds to 42 percent recovery of charge manganese.

6. In ladle/secondary refining, 10 percent of the manganese in added ferroalloys is lost in waste.

7. The yield of steel products from raw steel is 85 percent.

8. Of the metallic loss in casting/finishing, 90 percent is home scrap and 10 percent is waste.

(1) This is equivalent to ~ 57 percent steel production in BOP and ~ 43 percent in EAF.

Note that the average manganese content of hot metal is assumed to remain at 0.7 percent. The average Mn content of the charge scrap is 0.59% based on 28% home scrap containing 0.53% Mn and 72% purchased scrap containing 0.62% Mn.

steel products. Several specific processing improvements have also been assumed. Namely, that the relative share of hot metal in steel production decreases from a current value of 50 percent to a value of 40 percent; that the yield of raw molten steel from pig iron and scrap increases from a current value of 85 percent to a projected value of 90 percent; that the retention of manganese during steelmaking increases such that the manganese content in raw molten steel after oxidation refining is 0.3 percent rather than the current value of 0.2 percent; that the efficiency with which manganese is retained in molten steel during the addition of ferroalloys increases from a current value of 82 percent to a value of 90 percent; and that the yield of steel products from raw molten steel increases from a current value of 75 percent to a projected value of 85 percent. The technological developments required to achieve these improvements have been discussed in previous chapters and will be elaborated upon in a subsequent section. Figure 6 and Table XXII present the projected manganese inputs and outputs based on these changes. The corresponding projected values are 7.11 pounds manganese in ferroalloys per ton of raw molten steel and 8.36 pounds manganese per ton of steel products. This corresponds to reductions of 42 percent and 49 percent in ferroalloy manganese requirements expressed on the basis of a ton of raw steel and a ton of steel product, respectively. These reductions appear to be reasonable in view of the technological developments and trends cited in Chapter III. Therefore, we project a decrease in the ferroalloy manganese requirement to a value of 8.36 pounds per ton of shipments in the year-2000 on this basis.

For the purpose of refining the forecast of manganese requirements, Eq. (1) may be divided into a number of components that allow for the direct consideration of technological trends discussed in Chapter III. First, note that Eq. (2) obtains

$$M'' = M' / Y_1 \qquad - - - (2)$$

Figure 6. Projected (Year-2000) Representation of Manganese Inputs and Outputs in the Production of One Ton of Steel Products. All Numbers Are Expressed in Pounds of Manganese. See Table XXI for Additional Conditions.

Blast Furnace		Steelmaking		Ladle/Secondary Refining		Casting/Finishing	
In		In		In		In	
Iron Ore, Sinter[1]	8.51	Hot Metal (0.523t@0.7%Mn)	7.32	Raw Steel (1.176t@0.3%Mn)	7.06	Refd. Steel (1.176t@0.62%Mn)	14.58
Manganese Ore	1.25	Home Scrap (0.223t@0.53%Mn)	2.36	Ferroalloys	8.36		
		Purchased Scrap (0.561t@0.62%Mn)	6.96				
	9.76		16.64		15.42		14.58
Out		Out		Out		Out	
Hot Metal (0.523t@0.7%Mn)[2]	7.32	Raw Steel (1.176t@0.3%Mn)	7.06	Refd. Steel (1.176t@0.62%Mn)	14.58	Steel Products (1.000t@0.62%Mn)	12.40
Slag	2.44	Home Scrap (0.065t@0.3%Mn)	0.39	Waste	0.84	Home Scrap (0.158t@0.62%Mn)	1.96
		Slag and Dust	9.19			Waste	0.22
	9.76		16.64		15.42		14.58

Notes:

(1) Approximately 0.793 tons iron ore, sinter, and slag (containing ~ 62% Fe and ~ 0.54% Mn).

(2) If steelmaking requirements dictate a higher Mn content in hot metal it would be made up by either higher Mn content in ore/sinter or use of more steelmaking slag or use of more manganese ore. See discussion in text on limited use of recycled steelmaking slag and availability of iron ores with moderate manganese contents.

Table XXII

Summary of Projected (Year-2000) Representation of Manganese Inputs and Outputs in the Production of One Ton of Steel Products

Inputs of Manganese, Pounds		
Blast Furnace Iron Ore, Sinter*		8.51
Blast Furnace Manganese Ore		1.25
Purchased Scrap (0.561t@0.62%Mn)		6.96
Ferroalloys		8.36
	Total	25.08
Outputs of Manganese, Pounds		
Steel Products (1.000t@0.62%Mn)		12.40
Losses		
Blast Furnace Slag		2.44
Steelmaking Slag, Dust		9.19
Ladle/Secondary Refining Waste		0.84
Casting/Finishing Waste		0.22
	Total	25.09

*See footnotes to Figure 6.

In Eq. (2), M'' is the pounds of manganese added to steel in the form of ferroalloys per ton of steel products, M' is the pounds of manganese added to steel in the form of ferroalloys per ton of raw molten steel, and Y_1 is the yield of products from raw molten steel (tons product per ton of raw steel). M' is related to compositional and processing factors through Eq. (3).

$$M' = \frac{20}{R_1}\left\{(\%Mn)^* - (\%Mn)^o\right\} \qquad \text{- - - (3)}$$

In Eq. (3), $(\%Mn)^*$ is the required or specified manganese content in the finished steel (this varies by grade, but a domestic average may be taken), $(\%Mn)^o$ is the residual or finishing manganese content in raw molten steel after meltdown and primary oxidation steelmaking, and R_1 is the fractional recovery of manganese from added ferroalloys (including handling losses) in ladle and secondary refining.

Also, the residual manganese content in raw molten steel, $(\%Mn)^o$, is given by Eq. (4).

$$(\%Mn)^o = \frac{R_2}{Y_2} \cdot (\%Mn)' \qquad \text{- - - (4)}$$

In Eq. (4), $(\%Mn)'$ is the weighted average manganese content in the metallic iron charge of hot metal, purchased and home scrap, and D.R.I. to steelmaking furnaces (BOP and EAF), R_2 is the fractional recovery of manganese during meltdown and primary steelmaking, and Y_2 is the yield of raw molten steel from metallic charge materials during steelmaking (tons raw steel per ton of metallic charge).

Included in the calculation of $(\%Mn)'$ is the manganese content of hot metal, purchased and home scrap, and D.R.I. as shown in Eq. (5).

$$(\%Mn)' = \sum f_j\,(\%Mn)_j \qquad \text{- - - (5)}$$

In Eq. (5), f_j and $(\%Mn)_j$ represent the fractional share and manganese content respectively, of metallic iron units in steelmaking.[‡] The blast furnace hot metal contribution is an important term in Eq. (5). The manganese content in hot metal depends upon the manganese content of iron ores, the quantity of manganese ore charged, and upon operating factors that determine the degree of recovery of manganese in the hot metal. In recent years, about 1.4 pounds of manganese per ton of molten raw steel has been charged to blast furnaces in the form of manganese ore. This corresponds approximately to 2.38 pounds manganese (from manganese ore) per ton of hot metal. Based on a recovery of 75 percent, this yields only about 0.1 percent Mn in the hot metal. The balance of the manganese is derived from the manganese content of iron ores,* sinter, and recycled steelmaking slag.

Table XXIII presents current and projected (year-2000) values of the various terms in Eqs. (2) through (5) and estimates of manganese consumption. Entry M''' is the pounds of manganese added as manganese ore to blast furnaces per ton of steel products. Currently, M''' is about 1.9 and it is projected to have a value of 1.3 on the basis of the increasing fraction of steel produced from scrap in electric arc furnaces and the increasing yield, Y_1. See Appendix B.

The particular bases for the projections are given below.

$(\%Mn)'$, the average Mn content in the metallic charge to steelmaking, is expected to decline slightly because the manganese content of recycled scrap is expected to decline in accordance with decreased manganese specifications in carbon steels. This is discussed in connection with $(\%Mn)^*$. The current value of 0.66 for $(\%Mn)'$ is

‡See Appendix G for detailed discussion.

*Current U. S. and Canadian iron ore shipments contain about 0.3 percent Mn and 62.0 percent Fe. With Mn and Fe recovery at about 75 percent and 100 percent, respectively, and an Fe content in hot metal of about 94 percent, the manganese content of iron ore is equivalent to 0.34 percent Mn in hot metal.

Table XXIII

Current and Projected (Year-2000) Values of Terms in Eqs. (2) Through (5) and Estimates of Manganese Consumption in Iron and Steel Production (See Appendix B for Details)

Term	Definition	Current Value	Year-2000 Forecast*		
			Expected	"Best"	"Worst"
ω_e	Fraction of Steel From EAF	0.28	0.43	0.48	0.38
$(\%Mn)'$	Avg. % Mn in Chge. to Stmkg.	0.66	0.64	0.60	0.66
Y_2	Met. Yield in Prim. Stmkg.	0.85	0.90	0.93	0.87
R_2	Mn Recov. in Prim. Stmkg.	0.26	0.42	0.50	0.34
$(\%Mn)^\circ$	% Mn After Prim. Stmkg.	0.20	0.30	0.32	0.26
$(\%Mn)^*$	% Mn in Steel Products	0.70	0.62	0.56(1)	0.68(2)
R_1	Recov. of Mn in Ferroalloys	0.82	0.90	0.95	0.85
M'	Mn in Ferroalloys/Ton Raw Steel	12.20	7.11	5.85	9.93
Y_1	Met. Yield in Fing./Cstg.	0.75	0.85	0.90	0.80
M''	Mn in Ferroalloys/Ton Product	16.3	8.4	6.5	12.4
M'''	Mn in Mang. Ore/Ton Product	1.9	1.3	1.0	1.5
	Total Mn (Pounds/Ton Products)	18.2	9.7	7.5	13.9

Total Mn = M'' (From Ferroalloys) + M''' (From Manganese Ore)

*The best value is based on strong investment in available technology. The expected value is based on reasonable technical expectations as described in the text.

(1) Based on product mix of 90% carbon (0.5% Mn) and 10% alloy (1.1% Mn).

(2) Based on product mix of 70% carbon (0.5% Mn) and 30% alloy (1.1% Mn).

based upon estimated Mn contents in the 50/50 mix of hot metal and scrap as shown in Appendix B. The projected value of 0.64 is based on a 40/60 mix of hot metal and scrap, slightly decreased manganese content in scrap, and maintenance of 0.7% Mn in hot metal.*

The yield of raw molten steel from metallic charge in steelmaking is expected to increase from a value of 85 percent to a value of 90 percent (Y_2 = 0.85, 0.90) This improvement results in part from closer control of steelmaking processes, greater fraction of scrap use in steelmaking, and increased use of electric arc furnaces.

The recovery of manganese in steelmaking is expected to increase from a value of 25.8 percent to a value of 42.2 percent (R_2 = 0.26, 0.42) because of greater use of scrap and electric arc furnaces, increased use of bottom blowing and inert gas mixing in basic oxygen steelmaking, and general improvements in process control cited in Chapter III.

The expected residual manganese content in raw molten steel, $(\%Mn)^o$ is calculated from the three preceding quantities by means of Eq. (4). The value is expected to rise from 0.2 percent to 0.3 percent.

The average manganese content of domestic steel production is expected to decrease from a value of 0.7 percent to a value of 0.62 percent. The current value is estimated on the basis that current production is 85 percent carbon grade with an average Mn content of 0.64 percent and 15 percent alloy grade with an average manganese content of 1.04 percent. In the year-2000, it is estimated that 80 percent of production will be in carbon grades with an average Mn content of 0.5 percent and 20 percent of production will be in alloy grades with an average Mn content of 1.1 percent. This yields a projected weighted average of 0.62 percent. The general basis for these projections is presented in Chapter III.

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*It is expected that the decreasing Mn content in taconite concentrates will be compensated by iron ores containing higher Mn contents or manganese ore.

The recovery of manganese from ferroalloy additions is expected to rise from 82 percent to 90 percent (R_1 = 0.82, 0.90) primarily through better packaging, handling, and injection procedures, better process control, and inert gas protection of molten steel.

M', the pounds of manganese to be added as ferroalloys per ton of raw molten steel, is calculated from the preceding quantities by means of Eq. (3). The value is estimated to decrease from 12.2 to 7.1.

The yield of steel products from raw molten steel is expected to increase from a current value of about 75 percent to a value of 85 percent.

Therefore, Y_1 is assigned values of 0.75 and 0.85 in the respective years.

M'', the pounds of manganese added as ferroalloys per ton of steel products is calculated from the preceding two quantities by means of Eq. (2). It is estimated to decrease from a current value of 16.3 to a projected value of 8.4.

M''', the pounds of manganese added as manganese ore to the blast furnace per ton of steel products is expected to decrease from a current value of 1.9 to a value of 1.3 primarily because the hot metal share of steelmaking iron units is expected to decline.

The total manganese consumption in iron and steel production from ferroalloys and manganese ores (but not including iron ores, recycled scrap, and recovered waste materials), M'' plus M''', is projected to decrease from a current value of 18.2 to a value of 9.7 pounds per ton of steel products.

B. Comments on Scrap Use and Availability

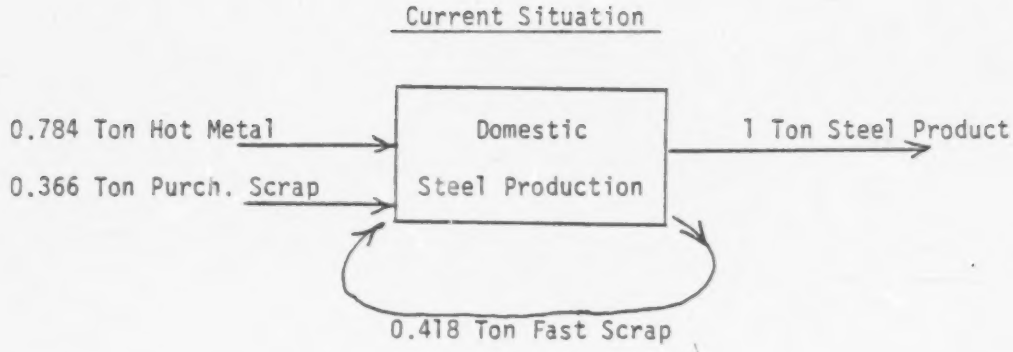
In the preceding section it has been assumed that the metallic iron inputs to steelmaking will shift significantly from hot metal to scrap during the next twenty years. In the expected case, the projected shift is from 50 percent hot metal--50

percent total scrap to 40 percent hot metal--60 percent total scrap. Figure 7 shows a simplified sketch of the current shares and forecast year-2000 shares of hot metal, home (fast) scrap, and purchased (recycled) scrap. These values are based on information given in Figures 5 and 6 and earlier sections. The share of purchased scrap is forecast to increase from a value of about 0.366 ton per ton of steel product to a value of about 0.561 ton per ton of steel product. While this shift is not a principal factor in determining manganese requirements because hot metal and recycled scrap contain comparable amounts of manganese,* it is an issue of major concern in connection with projections in the domestic steel industry. Therefore, a brief simplified version is presented for general background. Figure 8 is a schematic diagram appropriate for technical consideration of scrap generation and supply. Each year, a certain quantity of domestically produced and imported steel is "put into service," a certain quantity of steel in service is transferred to available scrap, and a certain quantity of available scrap is returned to domestic steel production and exported. The length of time that steel products remain in service and the degree of loss through scaling, rusting, abandonment, etc., are highly variable. If the average lifetime of steel in service is designated by y (number of years), then the transfer of steel from service to scrap in a current year is equal to the amount of steel placed in service during the year y-years earlier minus the loss. If the loss, ℓ, is expressed on a fractional basis, Eq. (6) obtains.

$$S_t \cong (D_y + I_y) \times (1 - \ell) = C_y (1 - \ell) \qquad - - - (6)$$

In Eq. (6), S_t is the steel transferred from service to scrap in the current year; D_y and I_y are the domestic and imported steel, respectively, placed in service

*The recovery of manganese from scrap in EAF steelmaking is greater than that of manganese from hot metal in BOP steelmaking.



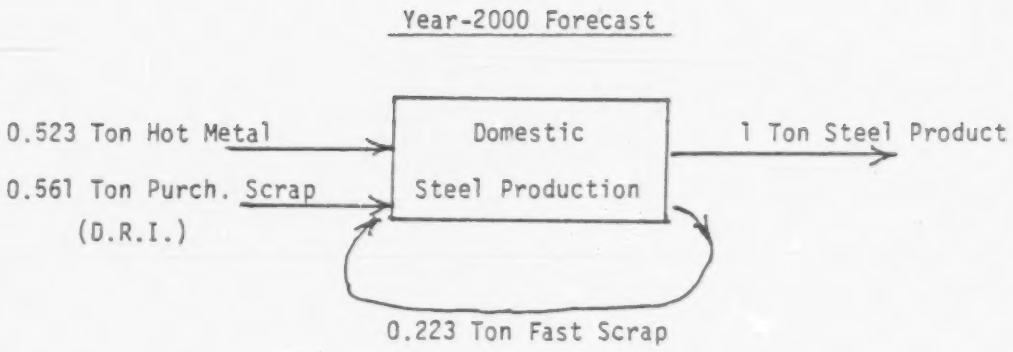


Figure 7. Simplified Diagrams of Metallic Iron Inputs to Domestic Steel Production.

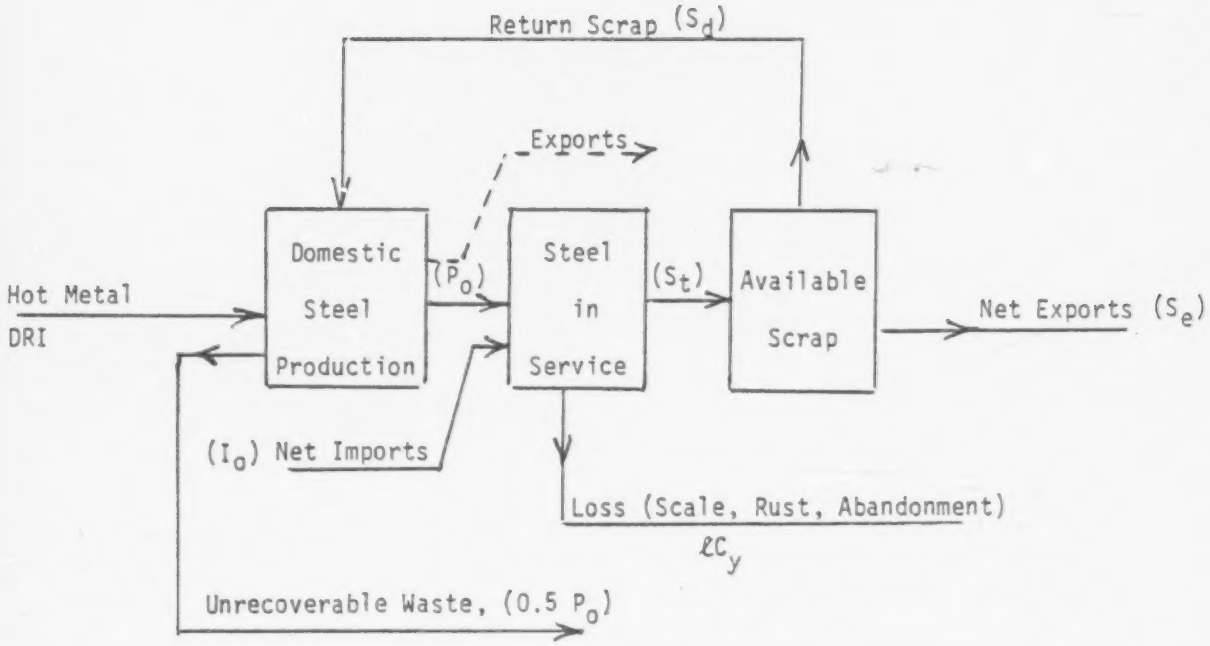


Figure 8. Simplified Representation of Steel Scrap Generation and Availability.

y-years earlier. Actually, $(D_y + I_y)$ represents the domestic consumption of steel, C_y, in the earlier year.‡ The domestic demand for scrap in the current year is determined, from a technical standpoint, by the demand for domestically produced steel and the share of domestic production derived from return scrap (in contrast to hot metal and D.R.I.). If it is assumed that the total quantity of available scrap remains approximately constant then S_t should be approximately equal to domestic consumption and exports of scrap in the current year. That is, Eq. (7) must obtain

$$S_d + S_e \cong S_t \qquad \text{- - - (7)}$$

In Eq. (7), S_d and S_e represent domestic consumption and exports of scrap, respectively, in the current year. Year to year imbalances between (S_d+S_e) and S_t and resulting scrap price fluctuations are anticipated but, on a longer term basis, these should cancel out. Domestic consumption of scrap, S_d, is determined by domestic production of steel, P_o, and the scrap share of domestic production, x. That is, Eq. (8) obtains

$$S_d = 1.05\ xP_o = 1.05\ x(C_o - I_o) \qquad \text{- - - (8)}$$

In Eq. (8), x is the fractional share of scrap in current domestic production, C_o is current domestic consumption, and I_o is current level of steel imports. By combination of the preceding equations, an expression for x can be obtained, Eq. (9).

$$x \cong \frac{C_y\,(1 - \ell) - S_e}{1.05(C_o - I_o)} \qquad \text{- - - (9)}$$

From a technical standpoint, the value of x calculated by means of Eq. (9) must be consistent with the current production facilities of the domestic steel industry; i.e., EAF and BOP capacities. Approximate values of x may be calculated by assuming a uniform growth rate for domestic steel production; i.e., Eq. (10).

‡ In a more refined analysis, C_y could represent an average annual consumption for a three-year period, i.e. $(C_{y-1} + C_y + C_{y+1})/3$.

$$C = C_y (1 + i)^y \qquad \text{- - - (10)}$$

Here, i is the annual fractional growth rate. If i is assigned a value of 0.01 (one percent annual growth rate) and y is given a value of 20 years, then $C_o = 1.22\ C_y$ and Eq. (9) may be rewritten as follows

$$x \simeq \frac{0.78\ (1 - \ell)\ C_o - S_e}{C_o - I_o} \qquad \text{- - - (11)}$$

If S_e and I_o are neglected, $x \simeq 0.78\ (1 - \ell)$. The loss of scrap, ℓ, is unknown. For heavy section steel products (structurals, plates, etc.) the loss is small (perhaps only 10 percent); but, for small section steel products (containers, wire, etc.), the loss is great (perhaps more than 50 percent). On average, it seems reasonable to assume a loss rate of about 35 percent which yields a value of x of 0.51. That is, about 51 percent of domestic steel production could, in principle, be derived from return scrap with the remainder derived from hot metal and D.R.I.[†] Actually, it is more appropriate to set a range such as 45-55 percent depending upon the particular values of S_e and I_o, and the values of i, y, and ℓ that are assumed.[†]

On this basis, a forecast that shows the hot metal share of metallic inputs to steelmaking declining from about 68 percent to about 48 percent over the next two decades (return scrap plus D.R.I. making up the balance) does not seem unreasonable. In effect, absolute consumption of hot metal would remain about constant while absolute consumption of return scrap plus D.R.I. would increase by about 90 percent. If the current 70/30 mix in BOP steelmaking continues, this corresponds to changes in the relative shares of steel production as follows: a decline from a current value of 71.4 percent to a value of 57.1 percent in BOP; and a corresponding increase from a current value of 28.6 percent to a value of 42.9 percent in EAF. Expressed another way, blast furnace and BOP capacity requirements

[†]If $I_o \simeq 0.25\ C_o$ and $S_e \simeq 0.10\ C_o$ (corresponding approximately to current values), then $x = 0.55$.

would remain unchanged while EAF capacity requirements would almost double over the two-decade period.

In the current period of depressed steel demand and idle capacity in all sectors, such considerations seem relatively unimportant; however, they have significance when viewed against the background of the historical trendline. Clearly, all such considerations are hypothetical because they do not include a proper assessment of incentives and financial resources for investments in steel production, nor do they include economic and competitive conditions throughout the World.

C. Summary

On the basis of the technological forecasts presented in this and the preceding chapter, it is estimated that the manganese consumption from manganese ore and ferroalloys (import share) expressed as pounds of manganese per ton of steel products will decrease from 18.2 to 9.7* in the period from 1982 to 2000 as shown in Table XXIV. This corresponds to an overall reduction of 47 percent or a compounded annual reduction rate of 3.5 percent for the period. If the demand for domestic steel products increases at an annual rate of 1.0 percent, the manganese requirements should decrease at an annual rate of about 2.5 percent. The uncertainties in these projections are obviously very great. The forecast has been prepared in a manner that makes it possible to alter and revise individual contributions.

It is not expected that manganese requirements will decrease at a uniform annual rate of 2.5 percent. Firstly, the technological changes will not be made in a uniform manner to yield a uniform rate of 3.5 percent for the decreased requirement of manganese per ton of product. Secondly, the demand for domestic steel products is not expected to follow a uniform trendline with an annual growth rate of 1.0 percent. Specific year by year changes will depend upon general

*The best and worst values shown in Table XXIV are 7.5 and 13.9, respectively.

Table XXIV

Summary of Projected Manganese Consumption
in U.S. Steel Production. Expressed in Pounds
of Manganese Per Ton of Steel Products

	Current (1981-2)	Projected, Year-2000 Expected	Best	Worst
Steelmaking Ferroalloys	16.3	8.4	6.5	12.4
Blast Furnace Manganese Ore	1.9	1.3	1.0	1.5
Import Sub-Total Input	18.2	9.7	7.5	13.9
Recycled (Purchased) Ferrous Scrap	5.1	7.0	6.9	6.7
Home Ferrous Scrap	4.7	2.4	1.4	3.5
Blast Furnace Iron Ore, Sinter	12.8	8.5	7.1	10.2
Total Input	40.8	27.6	22.9	34.3
Losses (Slag, Dust, Waste)	22.0	12.7	10.3	17.1
Retained in Steel Products*	14.0	12.4	11.2	13.6
Retained in Home Scrap	4.7	2.4	1.4	3.5
Total Output	40.7	27.5	22.9	34.2

ǂ It is assumed that all ferroalloys and manganese ores are derived from foreign sources. The import total is presented separately because of its obvious importance.

* The current and expected average manganese contents of steel products are 0.70% and 0.62%, respectively. The projected best and worst conditions are 0.56% and 0.68%, respectively.

economic factors and the ability of the domestic steel industry to make the required investments in new technology, i.e., continuous casting, modifications of oxygen steelmaking processes (bottom blowing, inert gas mixing, etc.) and electric arc steelmaking processes, ladle and secondary refining procedures, forming processes, and general process control and alloy specification contractions.

Finally, it should be pointed out that these forecasts differ markedly from those made by the National Material Advisory Board (1981) and U. S. Bureau of Mines (1980). In those studies, the forecast for total manganese (steel and non-steel) requirements from ferroalloys and manganese ores in the year-2000 is about 2.0 million tons (NMAB:1.9, USBM:1.8 to 2.4, most probable 2.0). In both studies, the basis for the forecast is that domestic production of steel will increase at an annual growth rate of 1.4 percent along a historical trendline and that the consumption of manganese per unit of product will not change significantly. Our assessment of technological factors suggests, on the contrary, that the consumption of manganese per unit of steel products is likely to decrease by a factor of two. If this proves to be the case, total manganese requirements in the year-2000 should be about 1.15 million tons (0.85 in steel and 0.3 in non-steel). This assumes that the projections of the USBM and NMAB for the non-steel sector are valid and that the assumed domestic steel production annual growth rate of 1.4 percent holds.

In summary, we forecast a decreasing manganese requirement in steel production and estimate that the requirement for manganese in the form of ferroalloy and manganese ore will be about 9.7 pounds of manganese per ton of domestically produced steel products in the year-2000. Under the most favorable conditions, the requirement could be as low as 7.5 pounds per ton and under the least favorable conditions as high as 13.9 pounds per ton. The most probable value of 9.7 is based on moderate technical expectations.

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Appendix A

Tables of specific manganese use in iron and steel production for the years 1962 to 1980. Values expressed by type of steel (carbon, alloy, stainless) and by form of manganese (high-carbon ferromanganese, low-carbon ferromanganese, silicomanganese, electrolytic manganese, Spiegeleisen, and manganese ore). Data for cast irons and other metallurgical uses are also shown. Tons of steel refers to short tons of raw molten steel.

See Tables XVII and XVIII in text for summaries.

GRADE	Hi C-Ferro	Lo C-Ferro	SiMn	Mn	Spigs
Carbon	601,232	46,899	75,450	3,140	16,561
Stnless & Hi Rst	855	2,332	3,504	6,657	13
Alloy	119,233	10,103	35,080	1,081	6,972
Miscellaneous	3,229	765	1,132	41	184
TOTAL	724,549	63,527	117,166	10,969	23,730
	×80%	×80%	×65%	×100%	×25%
Mn (tons)	579,639	50,822	76,158	10,969	5,933

	lbs. Mn	
ton steel	12.32	1.55 (1.4) 0.22 (0.2) 0.12 (0.1)

$$\text{TOTAL } \frac{\text{lbs. Mn}}{\text{ton steel}} = 14.71\ (13.7)^{*}$$

GRADE	Hi C-Ferro	Lo C-Ferro	SiMn	Mn	Spigs
Cast Irons	6,013	690	3,476	---	11,823
Steel Mill Rolls	797	198	545	---	510
Other Alloys	7,509	966	974	3,705	36
Miscellaneous	1,133	12	181	177	---
(nonsteel)TOTAL	15,442	1,856	5,176	3,882	12,419
	×80%	×80%	×65%	×100%	×25%
Mn (tons)	12,354	1,485	3,364	3,882	3,105

(nonsteel)TOTAL = 24,130 tons Mn

*Numbers in parentheses cited in USBM Minerals Yearbook

Mn CONSUMPTION
For 1981

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Briq
Carbon	671,630	72,582	23,247	4,989	15,518
Stnlss & Ht Rst	773	2,710	6,276	7,941	16
Alloy	124,752	15,379	38,317	1,274	7,989
Miscellaneous	3,388	103	1,005	47	121
TOTAL	800,543	91,023	178,845	14,251	23,644
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	640,434	59,218	90,249	14,251	5,911

	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Briq
lbs. Mn / ton steel	15.31	1.65	0.26	(0.3)	(0.1)

$$\text{TOTAL } \frac{\text{lbs. Mn}}{\text{ton steel}} = 14.33 \ (13.9)$$

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Briq
Cast Irons	7,018	738	3,677	---	9,634
Superalloys	1,120	194	684	---	575
Other Alloys	7,711	809	882	4,738	93
Miscellaneous	328	111	---	194	---
(nonsteel)TOTAL	16,377	1,942	5,243	4,932	10,264
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	13,102	1,554	3,408	4,932	2,566

(nonsteel)TOTAL = 25,562 tons Mn

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegel
Carbon	726,222	52,022	111,103	9,307	17,891
Stnlss & Hi Sst	913	4,341	9,346	9,026	132
Alloy	179,824	23,494	49,196	2,791	8,546
Miscellaneous	3,394	256	863	70	114
TOTAL	910,359	80,113	169,508	20,194	26,789
	×80%	×80%	×65%	×100%	×25%
Mn (tons)	728,287	64,090	110,180	20,194	6,697
lbs. Mn / ton steel	12.47	1.73	0.32	0.11	
	(11.8)	(1.6)	(0.3)	(0.1)	

TOTAL $\frac{\text{lbs. Mn}}{\text{ton steel}}$ = 14.63 (13.8)

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegel
Cast Irons	5,957	993	5,865	1	2,681
Steel Mill Rolls	1,695	256	774	---	224
Other Alloys	6,611	976	1,077	5,324	2
Miscellaneous	691	72	---	215	---
(nonsteel)TOTAL	14,954	2,297	9,716	5,540	10,902
	×80%	×80%	×65%	×100%	×25%
Mn (tons)	11,963	1,838	3,715	5,540	1,651

(nonsteel)TOTAL = 25,527 tons Mn

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegel
Carbon	719,063	91,563	115,941	7,469	16,345
Stnless & Ht Rst	1,234	3,478	8,359	3,880	42
Alloy	207,419	30,850	62,581	3,170	234
Miscellaneous	3,997	138	1,020	89	18
TOTAL	931,713	36,029	187,901	19,608	16,639
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	745,370	89,023	122,136	19,608	4,160

	Lbs. Mn
ton steel	12.39 / (11.2)	1.86 / (1.7)	0.30 / (0.3)	0.05 / (0.1)

$$\text{TOTAL } \frac{\text{Lbs. Mn}}{\text{ton steel}} = 14.61 \ (13.8)$$

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegel
Cast Irons	9,738	1,083	2,133	7	10,430
Steel Mill Rolls	1,870	260	753	---	827
Other Alloys	7,642	1,140	1,494	6,233	---
Miscellaneous	669	136	---	436	---
(nonsteel)TOTAL	19,919	2,641	4,380	6,676	11,319
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	15,935	2,113	2,847	6,676	2,830

(nonsteel)TOTAL = 30,301 tons Mn

GRADE	Hi C-Ferro	Lo C-Ferro	SiMn	Mn	Spigg
Carbon	711,407	64,292	106,069	6,292	16,489
Stnless & Ht Rst	1,244	3,e10	11,100	8,284	11
Alloy	203,525	35,695	51,244	2,768	3,573
Miscellaneous	5,461	629	1,482	19	3
TOTAL	921,640	104,140	149,895	17,363	20,106
	x80%	80%	x65%	x100%	x25%
Mn (tons)	737,312	83,312	110,432	17,363	5,027

	lbs. Mn / ton steel
	13.24
	(11.5)
	1.65
	(1.4)
	0.26
	(0.23)
	0.07
	(0.05)

TOTAL lbs. Mn / ton steel = 14.22 (13.2)

GRADE	Hi C-Ferro	Lo C-Ferro	SiMn	Mn	Spigg
Cast Irons	11,380	820	1,780	2	10,843
Steel Mill Rolls	1,577	207	813	---	793
Other Alloys	6,735	785	1,626	7,913	---
Miscellaneous	888	102	41	453	---
(nonsteel)TOTAL	20,630	2,913	4,262	7,475	11,686
	x80%	x30%	x65%	x100%	x25%
Mn (tons)	16,504	1,613	2,770	7,475	2,922

(nonsteel)TOTAL = 31,286 tons Mn

Mn CONSUMPTION
[illegible]

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegel
Carbon	602,487	82,053	105,468	5,606	12,956
Stnless & Ht Rst	1,040	2,693	9,791	6,554	---
Alloy	130,639	29,141	24,129	2,782	3,192
Hi-Spd & Tool	384	73	17	35	---
Miscellaneous	2,202	1,014	848	---	---
TOTAL	736,754	114,884	140,253	14,979	16,150
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	589,403	91,907	91,165	14,979	4,038

$$\frac{\text{lbs. Mn}}{\text{ton steel}}: \quad 10.71 \qquad 1.13 \qquad 0.24 \qquad 0.06$$
$$(11.7) \qquad (1.6) \qquad (0.25) \qquad (0.05)$$

$$\text{TOTAL } \frac{\text{lbs. Mn}}{\text{ton steel}} = 13.44 \ (13.6)$$

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegel
Cast Irons	11,681	1,273	2,592	36	10,350
Wld-Hrdfcng Matls	1,759	340	1,281	1,163	---
Other Alloys	3,678	204	96	5,706	---
Miscellaneous	97,377	14,180	10,683	2,157	2,869
(nonsteel)TOTAL	114,495	15,997	14,652	9,064	13,219
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	91,596	12,798	12,774	9,064	3,305

(nonsteel)TOTAL = 129,537 tons Mn

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegel
Carbon	706,392	76,428	107,890	6,362	11,429
Stnless & HL Rsf	1,256	2,339	10,221	6,903	---
Alloy	103,578	22,560	30,013	3,304	1,693
Tool	337	63	8	32	---
Miscellaneous	1,964	---	631	---	---
TOTAL	814,027	101,391	148,763	16,569	13,115
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	651,222	81,113	96,696	16,569	3,279

$$\frac{\text{lbs. Mn}}{\text{ton steel}} \quad 11.14 \qquad 1.47 \qquad 0.25 \qquad 0.05$$

$$\text{TOTAL} \quad \frac{\text{lbs. Mn}}{\text{ton steel}} = 12.91\ (13.6)$$

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegel
Cast Iron	9,944	1,829	2,901	5	13,920
Wld-Hrdfcng Metls	2,031	408	---	1,102	---
Other alloys	4,277	---	49	6,462	---
Miscellaneous	76,949	5,203	12,039	1,532	1,073
(nonsteel)TOTAL	93,201	7,440	15,869	9,101	14,993
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	74,561	5,952	10,315	9,101	3,748

(nonsteel)TOTAL = 104,077 tons Mn

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spieg
Carbon	756,718	82,305	96,630	7,273	11,788
Stnless & HS Hst	1,000	4,148	10,599	7,939	---
Alloy	114,438	25,824	29,064	2,885	1,906
Tool	472	22	---	---	---
TOTAL	872,628	112,140	136,293	18,097	13,694
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	698,102	89,712	88,591	18,097	3,424

	lbs. Mn / ton steel
	11.2
for steel	(11.0)

		lbs. Mn / ton steel	
	1.25	0.26	0.05
	(1.3)	(0.25)	(0.05)

TOTAL = 12.83 (13.0) lbs. Mn / ton steel

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegs
Cast Irons	12,299	2,017	5,991	---	7,991
Superalloys	758	139	---	345	---
Other Alloys	5,857	1,408	1,860	8,098	---
Miscellaneous	51,578	2,108	8,247	1,473	91
(nonsteel)TOTAL	70,282	5,662	16,098	9,916	8,082
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	56,226	4,530	10,464	9,916	2,021

(nonsteel)TOTAL = 83,157 tons Mn

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spigg
Carbon	713,691	81,570	87,845	4,837	11,167
Stucls & Ht Rst	1,830	1,931	8,371	6,689	---
Alloy	108,043	37,839	26,852	1,960	1,677
Tool	829	122	---	---	---
TOTAL	824,393	124,142	123,068	13,486	12,848
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	659,514	99,314	79,994	13,486	3,212

	lbs. Mn / ton steel
	11,04
	(11,0

		lbs. Mn / ton steel
		1,22
		(1,3)
		0,21
		(0,2)
		0,05
		(0,05)

TOTAL ---------- = 13,02 (13,1)
Ton steel

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spigg
Cast Irons	8,421	2,343	7,154	11	7,309
Superalloys	437	14	---	363	---
Other Alloys	5,387	1,172	1,838	9,410	---
Miscellaneous	32,423	1,799	6,440	1,212	111
(nonsteel)TOTAL	46,718	5,328	15,432	10,996	7,420
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	37,374	4,286	10,031	10,996	1,855

(nonsteel)TOTAL = 64,542 tons Mn

Mn CONSUMPTION
1967

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegel
Carbon	613,445	27,043	24,206	5,360	9,467
Stnless & Ht Rs*	2,969	5,213	6,213	7,205	---
Alloy	103,850	30,639	30,530	2,038	1,767
Tool	797	119	8	403	---
TOTAL	721,172	124,214	110,957	15,006	11,236
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	577,754	99,570	72,122	15,006	2,809
lbs. Mn / ton steel	11.53	1.20	1.30	0.25	0.05
	(11.2)	(1.3)	(1.3)	(0.25)	(0.05)

Ore used in Electric Furnace: 0.20 lb Mn/ton steel

$$\text{TOTAL } \frac{\text{lbs. Mn}}{\text{ton steel}} = 12.93 \ (13.0)$$

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegel
Cast Irons	17,636	1,103	3,512	8	3,250
Superalloys	350	---	---	340	1
Other Alloys	3,175	1,322	2,297	11,071	54
Miscellaneous	25,347	1,599	6,147	1,098	36
(nonsteel)TOTAL	48,548	5,064	11,956	12,517	8,441
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	38,834	4,051	7,771	12,517	2,110

(nonsteel)TOTAL = 65,283 tons Mn

Mn CONSUMPTION
1977

GRADE	Ht C-FeMn	Ln C-FeMn	SiMn	Mn	Shapes
Carbon	659,822	99,824	91,067	7,078	9,837
Stnless & Ht Rst	4,197	5,232	3,371	6,483	---
Full Alloy	76,729	28,496	16,682	1,216	1,141
HSLA	59,445	8,358	6,544	375	141
Electric	324	263	817	8	---
Tool	1,175	342	27	676	---
TOTAL	801,744	142,892	113,508	15,836	11,153
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	641,395	114,314	73,780	15,836	2,788
lbs. Mn / ton steel	11.81	1.11	0.24	0.04	
	(11.0)	(1.2)	(0.25)	(0.05)	

Ore used in steelmaking: 0.10 lb Mn/ton steel
Ore used in blast furnace: 1.20 lb Mn/ton steel

TOTAL (lbs. Mn / ton steel) = 14.00 (13.8)

GRADE	Ht C-FeMn	Ln C-FeMn	SiMn	Mn	Shapes
Cast Irons	16,231	1,936	3,660	23	6,461
Superalloys	220	20	---	338	---
Other Alloys	4,668	1,130	2,393	12,685	4
Miscellaneous	989	1,098	4,692	1,067	
(nonsteel)TOTAL	22,018	4,384	10,745	14,113	6,467
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	17,638	3,427	6,984	14,113	2,117

(nonsteel)TOTAL = 44,279 tons Mn

Grade	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegel
Carbon	[illegible]	[illegible]	4,630	8,133	11,113
Stainless & Ht Res	5,119	3,194	12,456	7,080	1
Full Alloy	81,164	24,552	39,929	1,784	1,653
HSLA	1,350	[illegible]	8,019	712	129
Electric	430	293	1,145	17	---
Tool	1,544	[illegible]	51	650	---
TOTAL	924,131	161,566	146,231	18,876	12,892
	×80%	×80%	×65%	×100%	×25%
Mn (tons)	739,465	129,253	95,050	18,876	3,223

	lbs. Mn
ton steel	13.22
	(13.1)
	1.26
	(1.3)
	0.25
	(0.25)
	0.01
	(0.05)

Ore used in steelmaking: 0.20 lb Mn/ton steel
Ore used in blast furnace: 1.10 lb Mn/ton steel

TOTAL lbs. Mn / ton steel = 14.57 (14.9)

Grade	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegel
Cast Irons	19,295	1,944	4,907	39	8,695
Superalloys	731	---	---	358	---
Other Alloys	4,940	1,481	2,785	14,595	24
Miscellaneous	234	1,080	5,096	1,375	---
(non-steel) TOTAL	26,200	4,505	12,788	16,367	8,721
	×80%	×80%	×65%	×100%	×25%
Mn (tons)	20,960	3,604	8,312	16,367	2,180

(non-steel) TOTAL = 51,423 tons Mn

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spieg
Carbon	737,013	111,333	100,750	3,157	9,829
Stnless & Ht Rst	7,178	3,679	12,643	5,323	1
Full Alloy	59,299	20,479	44,504	1,391	901
HSLA	26,572	4,841	3,639	1,308	---
Electric	458	283	260	31	---
Tool	1,739	560	16	649	---
TOTAL	832,829	150,350	157,512	17,853	10,785
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	746,263	134,280	102,383	17,853	2,696

lbs. Mn / ton steel: 11.10 (11.5) | 1.41 (1.4) | 0.25 (0.25) | 0.04 (0.05)

Ore used in steelmaking: 0.10 lb Mn/ton steel
Ore used in blast furnace: 1.20 lb Mn/ton steel

TOTAL lbs. Mn / ton steel = 14.85 (14.5)

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spieg
Cast Irons	16,660	2,573	10,677	115	7,893
Superalloys	439	50	90	318	---
Other alloys	5,049	1,070	3,945	15,072	39
Miscellaneous	759	1,260	5,242	1,390	---
(nonsteel)TOTAL	22,907	5,363	19,954	16,895	7,932
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	18,326	4,290	12,970	16,895	1,983

(nonsteel)TOTAL = 54,464 tons Mn

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegs
Carbon	592,876	80,795	87,385	4,506	5,103
Stnless & HR Fsl	4,043	2,541	5,808	4,030	3
Full Alloy	31,623	25,060	39,192	833	617
HSLA	97,541	9,792	7,305	640	---
Electric	313	149	775	2	---
Tool	1,581	218	15	247	---
Miscellaneous	455	384	2,657	---	---
TOTAL	728,432	125,890	143,237	12,258	8,721
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	582,746	101,504	93,104	12,258	2,180

	Lbs. Mn
Lbs. Mn / Ton steel	11.73
Ton steel	(11.6)

	Lbs. Mn
	1.60
	(1.6)

	Lbs. Mn
	0.21
	(0.2)

	Lbs. Mn
	0.04
	(0.03)

Ore used in steelmaking: 0.02 lb Mn/ton steel
Ore used in blast furnace: 1.30 lb Mn/ton steel

	Lbs. Mn
TOTAL	---------- = 14.40 (14.6)
	Ton steel

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegs
Cast Irons	14,389	4,518	12,933	189	5,486
Superalloys	348	---	---	280	---
Other Alloys	4,239	1,408	3,788	8,750	39
Miscellaneous	363	950	1,501	932	---
(nonsteel)TOTAL	19,339	6,876	17,322	10,151	5,021
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	15,471	5,501	11,259	10,151	1,380

(nonsteel)TOTAL = 43,762 tons Mn

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegs
Carbon	601,421	109,426	87,888	7,238	4,100
Stnl s & HS Rst	7,230	1,800	7,737	5,838	---
Full alloy	77,500	20,443	27,222	1,027	328
HSLA	45,643	2,841	7,160	617	---
Electric	197	146	570	17	---
Tool	1,772	228	29	633	---
Miscellaneous	300	227	2,962	---	---
TOTAL	734,058	137,913	133,568	15,268	4,430
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	587,246	110,330	86,819	15,268	1,108

Use: Mn

---

ton steel (16.8) (1.4) (0.2) (0.01)

1.36 0.24 0.02

Ore used in steelmaking: 0.01 lb Mn/ton steel
Ore used in blast furnace: 1.00 lb Mn/ton steel

Use: Mn

TOTAL ---------- = 18.32 (18.2)

ton steel

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spiegs
Cast Irons	16,785	1,296	16,006	134	4,960
Superalloys	249	---	---	316	---
Other Alloys	4,277	1,772	3,003	11,365	22
Miscellaneous	379	945	1,951	1,043	---
(nonsteel)TOTAL	21,690	4,013	20,960	12,858	4,980
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	17,352	3,210	13,624	12,858	1,244

(nonsteel) TOTAL = 48,288 tons Mn

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spieg
Carbon	583,921	[illegible]	81,293	7,827	5,860
Stnless & Ht Rst	10,512	1,[illegible]	7,502	3,257	---
Full Alloy	81,391	[illegible]	26,389	967	130
HSLA	49,216	10,295	7,647	317	---
Electric	304	137	474	9	---
Tool	571	[illegible]	55	450	---
Miscellaneous	270	249	2,803	---	---
TOTAL	726,824	134,313	126,463	13,417	5,990
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	581,459	[illegible]	82,201	13,417	1,498

	Tons Mn			
lbs. Mn / ton steel	10.88	1.31	0.21	0.02
	(10.4)	(1.3)	(0.2)	(0.02)

Ore used in steelmaking: 0.03 lb Mn/ton steel
Ore used in blast furnace: 1.3 lb Mn/ton steel

TOTAL ---------- Tons Mn / ton steel = 13.86 (13.5)

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Spieg
Cast Irons	18,673	1,637	16,514	117	838
Superalloys	305	21	---	204	---
Other Alloys	2,923	1,421	2,412	12,246	1
Miscellaneous	564	296	2,370	970	---
(nonsteel)TOTAL	21,785	3,875	21,296	13,537	842
	x80%	x80%	x65%	x100%	x25%
Mn (tons)	17,428	3,100	13,842	13,537	211

(nonsteel)TOTAL = 48,148 tons Mn

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Sales
Carbon	654,201	11[illegible],331	94,444	8,242	4,014
Stnless & Ht Res	13,338	1,341	7,527	2,530	---
Full Alloy	81,053	17,021	28,799	1,530	22
HSLA	36,141	11,819	9,795	1,379	---
Electric	---	156	482	10	---
Tool	649	70	53	129	---
Miscellaneous	152	431	2,603	---	---
TOTAL	806,543	130,571	143,614	13,861	4,036
	=80%	=80%	=65%	=100%	=25%
Mn (tons)	645,[illegible]	120,4[illegible]	93,349	13,861	1,009

	lbs. Mn / ton steel
	1.17
	(1.4)
	1.36
	(1.4)
	0.20
	(0.2)
	0.01
	(0.01)

One used in steelmaking: 0.01 lb Mn/ton steel
One used in blast furnace: 1.40 lb Mn/ton steel

	lbs. Mn / ton steel	
TOTAL	----	1.15 (1.3)

GRADE	Hi C-FeMn	Lo C-FeMn	SiMn	Mn	Sales
Cast Irons	22,437	1,474	16,369	51	---
Superalloys	297	22	---	177	--
Other Alloys	2,074	1,122	2,598	13,213	---
Miscellaneous	401	900	1,731	902	---
(ingot steel)TOTAL	25,171	3,533	20,694	14,373	---
	=80%	=20%	=65%	=100%	=25%
Mn (tons)	20,137	2,830	13,451	14,373	---

(ingot steel)TOTAL = [illegible],721 tons Mn

GRADE	Ht C-FeMn	Lo C-FeMn	SiMn	Mn	Steel
Carbon	630,450	118,800	95,190	7,415	489
Stnless & Ht Rst	14,231	1,227	8,858	2,245	---
Mull Alloy	94,141	17,503	35,472	1,180	---
HSLA	39,135	13,911	9,157	1,429	--
Electric	1	149	104	6	---
Tool	300	50	46	139	---
Miscellaneous	502	586	3,179	10	---
TOTAL	739,264	151,785	151,506	13,023	489
	80%	20%	65%	100%	25%
Mn (tons)	649,411	121,412	98,479	13,023	122

	Lbs. Mn
Lbs. Mn / ton steel	11.15
	(11.6)
	1.44
	(1.5)
	0.19
	(0.2)

Ore used in steelmaking: 0.01 lb Mn/ton steel
Ore used in blast furnace: 1.40 lb Mn/ton steel

	Lbs. Mn / Ton Steel
TOTAL	14.20 (14.1)

GRADE	Ht C-FeMn	Lo C-FeMn	SiMn	Mn	Steel
Cast Irons	20,220	1,200	15,715	14	---
Superalloys	247	---	---	236	---
Other Alloys	1,887	478	2,386	13,938	---
Miscellaneous	304	807	2,293	904	---
(nonsteel)TOTAL	22,958	2,385	20,395	15,092	---
	80%	20%	65%	100%	25%
Mn (tons)	18,384	2,074	13,257	15,092	---

(nonsteel)TOTAL 48,811 tons Mn

Grade	Hi C-Ferro	Lo C-Ferro	SiMn	Mn	Briq
Carbon	501,444	93,684	92,196	5,706	301
Stnless & Ht R-L	10,290	840	5,458	2,353	---
Full Alloy	24,290	13,965	32,873	851	---
HSLA	91,253	11,835	8,319	1,006	---
Electrom	2	79	69	1	---
Tool	471	81	42	167	---
Miscellaneous	370	11	1,015	1	---
TOTAL	645,504	120,495	139,970	10,083	301
	76%	14%	16%	1100%	0.0%
Mn (tons)	31,198	4,153	20,681	10,083	78

	lbs. Mn
ore used in steelmaking	1.63
ton steel	(1.6)

Ore used in steelmaking: 0.0 lb Mn/ton steel
Ore used in blast furnace: 1.0 lb Mn/ton steel

	lbs. Mn / ton steel
TOTAL	15.77 (15.6)

Grade	Hi C-Ferro	Lo C-Ferro	SiMn	Mn	Briq
Cast Irons	15,317	1,050	11,695	8	---
Superalloys	242	---	---	193	---
Other Alloys	1,579	491	2,576	14,112	2
Miscellaneous	3,482	594	1,576	582	---
(nonsteel)TOTAL	20,615	2,135	15,847	14,895	2
	76%	80%	95%	100%	25%
Mn (tons)	14,462	1,708	10,301	14,895	---

(nonsteel)TOTAL 41,314 tons Mn

Appendix B

DETAILED BASIS FOR MANGANESE CONSUMPTION CALCULATIONS

In the calculations summarized in Table XXIII, a number of technical terms have been introduced. A detailed procedure is presented in this appendix. A full description of the nomenclature follows:

γ_b = The fraction of scrap in the metallic charge to BOP steelmaking processes.

$(1-\gamma_b)$ = The fraction of hot metal in the metallic charge to BOP steelmaking processes.

γ_e = The fraction of scrap and DRI in the metallic charge to EAF steelmaking processes.

$(1-\gamma_e)$ = The fraction of hot metal in the metallic charge to EAF steelmaking processes.

ω_e = The fraction of raw steel produced in EAF steelmaking processes.

$(1-\omega_e)$ = The fraction of raw steel produced in BOP steelmaking processes.

f_{hm} = The fraction of hot metal in metallic charge to all steelmaking processes.

f_{fs} = The fraction of fast scrap in metallic charge to all steelmaking processes.

f_{ps} = The fraction of purchased scrap in metallic charge to all steelmaking processes. $f_{ps} = 1 - f_{hm} - f_{fs}$

r_s = The fraction of metallic loss in primary steelmaking that is directly recoverable as fast scrap.

r_c = The fraction of metallic loss in casting/finishing that is directly recoverable as fast scrap.

$(\%Mn)_{hm}$ = The manganese content in hot metal.

$(\%Mn)_{fs}$ = The average manganese content in fast scrap.

$(\%Mn)_{fss}$ = The average manganese content of fast scrap from primary steelmaking. Note that this must equal $(\%Mn)^{\circ}$.

$(\%Mn)_{fsf}$ = The manganese content of fast scrap from finishing casting. Note that this must equal $(\%Mn)^{*}$.

$(\%Mn)_{ps}$ = The average manganese content of purchased scrap.

$(\%Mn)'$ = The average manganese content in the metallic charge to steelmaking (see Eq. 5).

$(\%Mn)^{\circ}$ = The average manganese content in raw steel after steelmaking but before ladle/secondary additions.

$(\%Mn)^{*}$ = The average manganese content of finished steel products.

R_1 = The fractional recovery of manganese from ferroalloys added in ladle/secondary refining.

R_2 = The fractional recovery of manganese in steelmaking (manganese in raw steel divided by manganese in metallic charge to steelmaking).

Y_1 = The yield of products from raw steel (tons product per ton raw molten steel).

Y_2 = The yield or raw molten steel from metallic charge to steelmaking.

M' = The pounds of manganese in the form of ferroalloys added per ton of raw molten steel.

M'' = The pounds of manganese in the form of ferroalloys added per ton of finished steel products ($M'' = M'/Y_1$).

M''' = The pounds of manganese in the form of manganese ore used in the blast furnace per ton of finished products.

Of the foregoing quantities, the following are treated as adjustable parameters from which all others may be calculated:

γ_b	$(\%Mn)^*$
γ_e	R_1
ω_e	R_2
r_s	Y_1
r_c	Y_2
$(\%Mn)_{hm}$	
$(\%Mn)_{ps}$	

The calculations begin with the determination of $(\%Mn)'$, the second entry in Table XXIII.

From Eq. 5,

$$(\%Mn)' = f_{hm}(\%Mn)_{hm} + f_{ps}(\%Mn)_{ps} + f_{fs}(\%Mn)_{fs} \tag{5a}$$

But,

$$f_{hm} = (1-\gamma_b)\ (1-\omega_e) + (1-\gamma_e)\ \omega_e \tag{5b}$$

$$f_{fs} = r_s\ (1-Y_2) + r_c\ Y_2\ (1-Y_1) \tag{5c}$$

$$f_{ps} = 1 - f_{hm} - f_{ps} \tag{5d}$$

$$(\%Mn)_{fs} = \frac{(r_s)(1-Y_2)(\%Mn)^\circ + r_c\ Y_2(1-Y_1)(\%Mn)^*}{f_{fs}} \tag{5e}$$

$$(\%Mn)^\circ = \frac{R_2}{Y_2}\ (\%Mn)' \tag{5f}$$

By combination of Eqs. 5a through 5f, (%Mn)' is found in terms of γ_b , γ_e , ω_e , r_s , r_c , $(\%Mn)_{hm}$, $(\%Mn)_{ps}$, (%Mn)* , R_2 , Y_1 , and Y_2 . In all of the calculations summarized in Table XXIII, constant values were assigned to $\gamma_b = 0.3$, $\gamma_e = 1.0$, $r_s = 0.5$, $r_c = 0.9$, and $(\%Mn)_{hm} = 0.7$. In addition, it has been assumed that $(\%Mn)_{ps}$ = (%Mn)*. Hence, the only variables treated were ω_e , (%Mn)* , R_1 , R_2, Y_1 and Y_2. As an illustration of the calculation of (%Mn)' consider the current situation shown in Table XXIII for which the following values of the variables were assigned.

$$\omega_e = 0.28$$

$$(\%Mn)^* = 0.7$$

$$R_1 = 0.82$$

$$R_2 = 0.26$$

$$Y_1 = 0.75$$

$$Y_2 = 0.85$$

Then, from Eqs. 5b through 5d,

$$f_{hm} = 0.504$$

$$f_{fs} = 0.266$$

$$f_{ps} = 0.230$$

Note that this represents a charge of 50 percent hot metal and 50 percent scrap to all steelmaking. To obtain the total quantities of each item required per ton of steel product, multiply f_j by $1/Y_1Y_2$ or 1.569. (See Fig. 5). Then, (%Mn)° is expressed in terms of (%Mn)' through Eq. 5f.

$$(\%Mn)^\circ = 0.347\ (\%Mn)'$$

and, $(\%Mn)_{fs}$ is expressed in terms of (%Mn)' through Eq. 5e.

$$(\%Mn)_{fs} = (0.098)\ (\%Mn)' + 0.504$$

Then, from Eq. 5a, we have

$$(\%Mn)' = 0.353 + 0.161 + .134 + .026(\%Mn)'$$

$$(\%Mn)' = 0.648 + 0.026\ (\%Mn)'$$

and, $$(\%Mn)' = 0.66$$

Once (%Mn)' is calculated in the foregoing manner for the assumed values of the parameters, the subsequent calculations leading to M'' and the total Mn requirement are carried out as described in the body of Section IV, pp. 60-67. Also,

$$M''' = (m)\ \frac{f_{hm}}{Y_1 Y_2}$$

where m = pounds of manganese in the form of manganese ore consumed per ton of hot metal produced in the blast furnace. Then, the total virgin manganese requirement from ferroalloys and manganese ore per ton of steel product is given by $(M'' + M''')$.

The current and projected values of m , the pounds of manganese as manganese ore charged to the blast furnace per ton of hot metal, are estimated to be 2.4.